Research Report
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EVALUATION OF CORED SPECIMENS FROM TIMBER CAISSON BENEATH PIER NO. 2 OF THE US 25 BRIDGE OVER THE OHIO RIVER BETWEEN COVINGTON AND CINCINNATI F141(1)

KYP-56; HPR-1(6), Part III

by

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Division of Research
DEPARTMENT OF HIGHWAYS
Commonwealth of Kentucky

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INTRODUCTION

Pier No. 2 of the former C&O Bridge at Covington is off-shore from the Kentucky side of the Ohio River. It was built in 1887. In 1927, this pier was extended downstream to support a new railroad bridge. The other three piers remained independent. The original structure was then converted to highway use and was purchased by the Commonwealth of Kentucky in 1937. In 1968, an engineering analysis of the superstructure indicated critical deficiencies in terms of "safety factors", and the bridge was closed to all traffic. Subsequently, various plans for reconstruction came under consideration. Of greatest significance here is the consideration toward re-use of Pier No. 2 -- jointly with a new highway bridge and the existing railroad bridge. Cost estimates appeared persuasive; the structural feasibility remained dependent upon the integrity of the pier -- more specifically, the worthiness of the masonry, concrete, and the underlying timber caisson.

Prior to removal of the steel superstructure (fall of 1970), vertical cores were extracted from Pier No. 2 for evaluation. This report concerns the evaluation of specimens of wood from the timber caisson.

The substructure construction was described by Wm. H. Burr, in the Transactions of the American Society of Civil Engineers, Vol. XXIII, 1890; a copy is appended hereto for convenient reference; Plate XIII, therein, is most pertinent.

PERMANENCE OF BURIED TIMBER FOUNDATIONS

Timber foundations under masonry structures have been employed throughout recorded history. Wood buried below the oxygen-diffusion zone is preserved through oxygen starvation of fungi and bacteria. Decay may proceed for a short time. Anaerobic bacteria have an implied capability of regenerating and utilizing oxygen from host organic matter; however, the digestive cycle is likely to become unbalanced, poisoned, or at least arrested. Obviously, buried woods do not persist forever. Some commentaries indicate that wood pilings suffice for 80 to 100 years; others suggest hundreds of years. However, the tenure of structures in this country rarely exceeds a hundred or more years. American engineers do not usually build to withstand the ages. Obsolescence limits tenure. European engineers strive for greater tenure. The main piers of the Roebling suspension bridge immediately upstream from the C&O site, was begun in 1857; the piers are founded on hewed log mats set on gravel 10-12 feet above bedrock. The bridge was opened to traffic January 1, 1867.

EVALUATION OF WOOD SPECIMENS

Consideration of use of Pier No. 2 in the new structure afforded a rare opportunity for historical but purposeful inspection of the present condition of the wood. Discovery of decay or rot would probably have led to immediate rejection of the alternative. Upon recovery, the cores appeared frayed and severely damaged. Later, when sawed along the diameter, bright wood appeared. A slightly acrid odor was detectable; but there was also a distinctive scent of newly-cut wood. Specimens of pine were distinctly odorous. A specimen of poplar was recovered but was examined by the Forest Products Laboratory only (See Appendix II). In the main, the cores consisted of white oak. Not all of the specimens were bright (yellowish); some were dark -- approaching gun-metal blue or dark gray. Miniature specimens were cut from the cores and subjected to compressive loading. Stress-strain curves are presented here. Comparative stress-strain curves obtained from new white oak wood are also provided. Copies of the core logs are appended.

Figure 1 is a composite photograph of the three cores received for evaluation. Attention is directed to the incidental recovery of a wrought iron pin in the upper portion of the NW core.

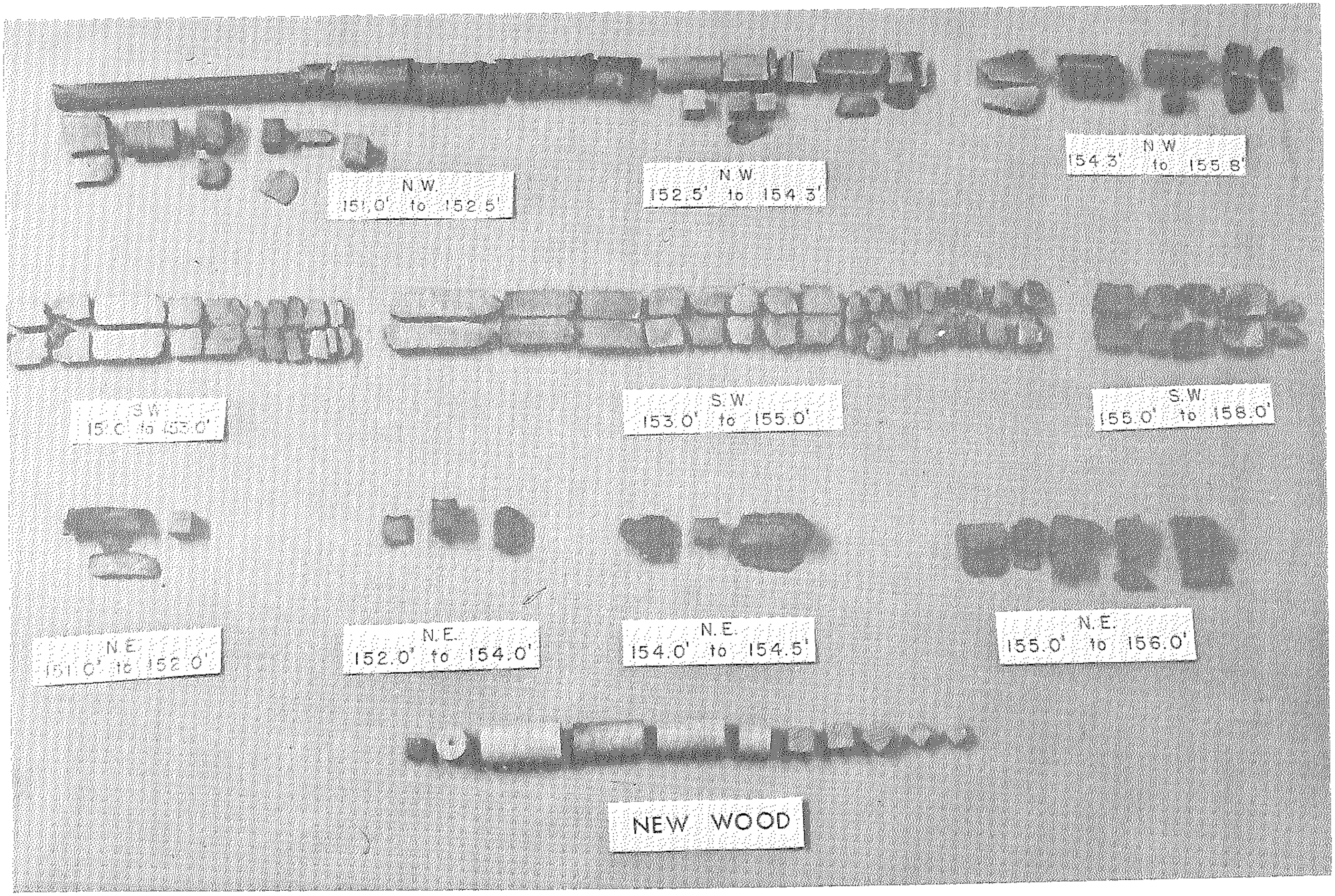


Fig. 1: Composite Photo of Cores Received for Evaluation. Recovery of wrought iron pin in NW core was incidental.

SIMPLE COMPRESSION TESTS

Small cubical specimens, ranging from 0.7 in. to 1.2 in. in size, were cut from the cylindrical cores. Except for slight surface drying during fine shaping, the specimens were maintained in a wet condition until the compression tests were completed. A specimen of bright wood in test is shown in Fig. 2. All compression tests were made perpendicular to the grain. There was noticeable weeping of water from the pores.

Fig. 3 shows a specimen of dark wood distorted (residual) by compression. None of the specimens ruptured, split, or tore; all specimens, including new wood, exhibited a yield point followed by strain hardening. The resulting stress-strain relationships are shown in Fig. 4. The minimum yield point occurred at about 350 psi; the yield stress of new wood was in the order of 2 to 2.5 times that of old wood. The handbook yield point for white oak, at 70% moisture (green and unseasoned), is 850 psi.

NOTE: New wood specimens were soaked in water for five days before testing.

Differences (between new and old wood) in the number of annual rings per inch are also shown in Fig. 5. Because of these differences, the woods are not directly comparable in terms of strength. The new wood specimens contain a significantly greater proportion of late wood growth and are thereby adjudged to be superior in strength. Due to an assumed improbability of finding new wood comparable in anatomical attributes to the old wood, it was decided to air dry specimens of old wood and to make strength tests in that condition and to compare those strengths with handbook values for new wood. The average handbook value for white oak in this condition is 1410 psi. The strengths of the two specimens selected (one bright wood and one dark wood) are shown in Fig. 5. By this comparison, the old wood would necessarily be adjudged equal to average new wood. This interpretation minimizes any effects otherwise attributable to decay. It does not suffice to explain the low, wet strength of the old wood. It is suggested that moisture contents approaching a state of supersaturation -- possibly somewhat greater than that of green wood and of osmotic origin -- affects the wet strength. The effect of swelling, attending unloading (coring), on moisture content was not determined. However, a small but significant swell pressure was measured upon re-immersion (discussed subsequently).

Fig. 2: Specimen of Bright White Oak in Compression. Note weeping from pores near base of specimen.

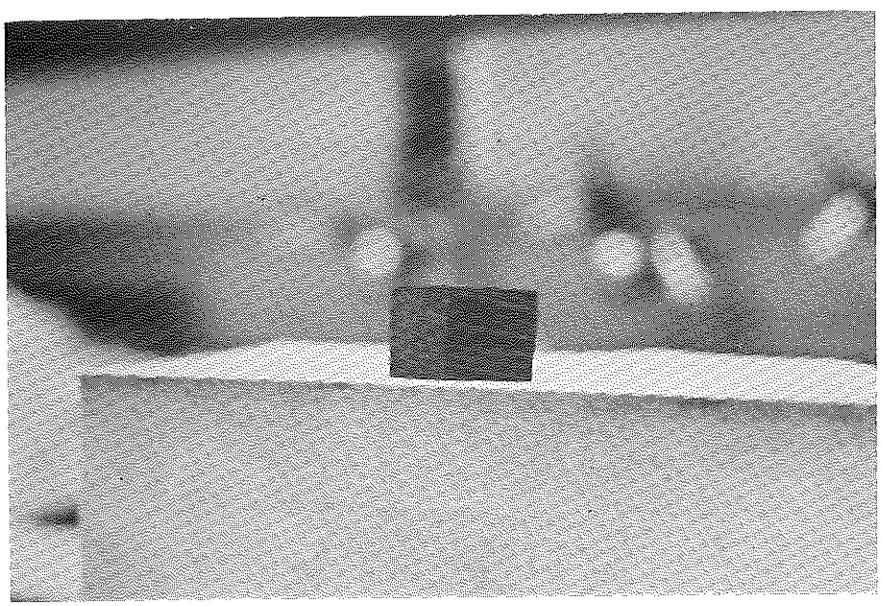


Fig. 3: Dark White Oak Specimen Showing Residual Distortion Following Severe Compression.

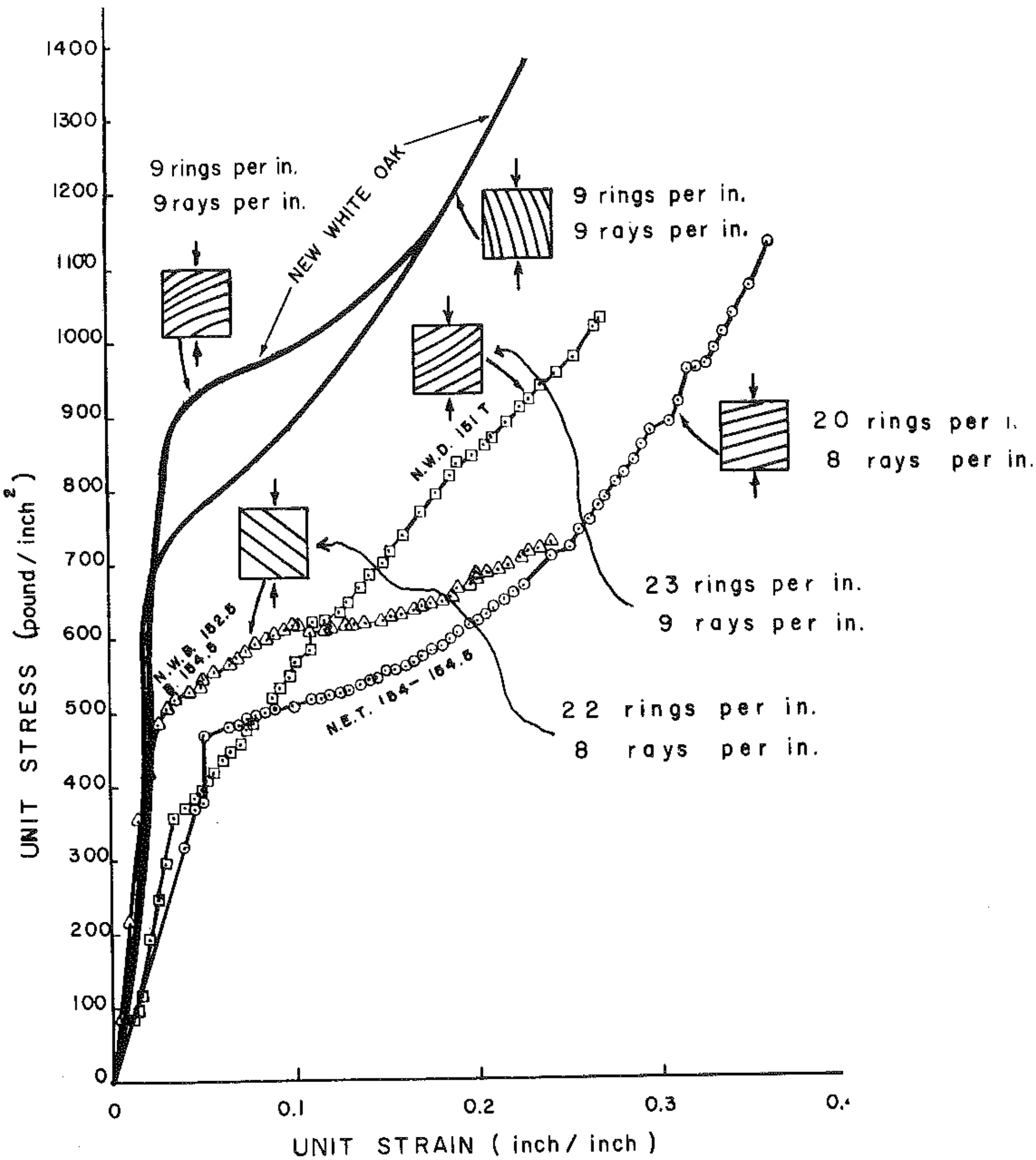


Fig. 4: Stress-Strain Relationships Obtained from Old Wood and New Wood (saturated).

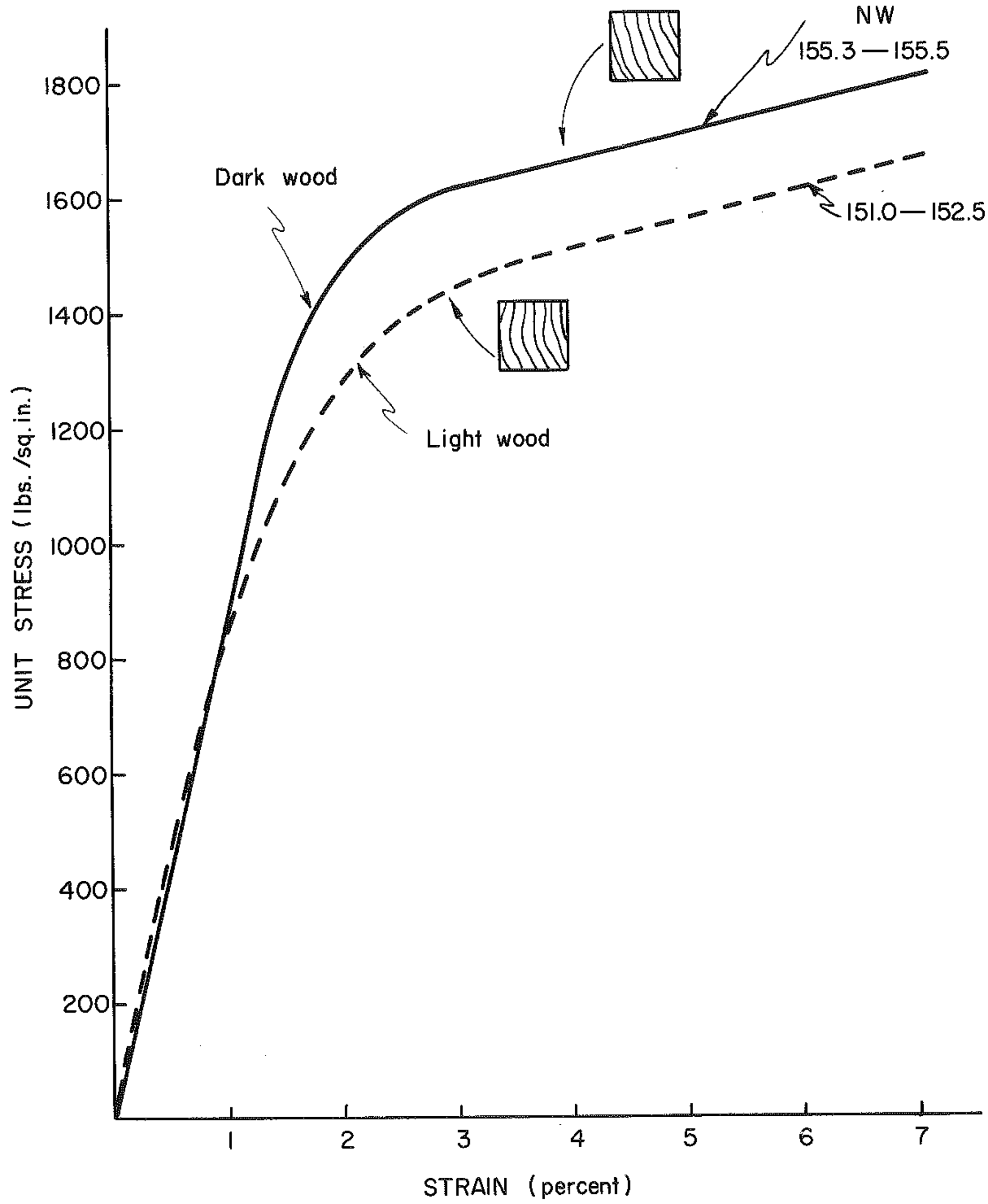


Fig. 5: Stress-Strain Relationship Obtained from Air-Dry Specimens of Old Wood.

SWELL AND RELAXATION TESTS (TRIAXIAL)

A cylindrical specimen of dark wood; 2.72 in. x 1.30 in., was placed in a triaxial test chamber and surrounded by water under 20 psi pressure; the specimen was restrained in the axial direction by a nominal preload of 1 lb. and a load-cell. After 24 hrs., the swell pressure was 6.1 lbs. The load was increased to 50 lbs.; and, under constant strain, the specimen was allowed to relax for 1 to 6 hrs.; the residual load then was recorded. Then the load was removed and the residual strain recorded (usually 20 to 30 minutes after unloading). This procedure was repeated with five additional, 50-lb. increments of loads; the maximum load was 300 lbs. The resulting strain-hysteresis data were plotted as shown in Fig. 6. The relaxation loads after a time (1 to 6 hrs.) are shown plotted against applied load, in Fig. 7. There, the deviations from the line of equality indicate the relative creep-relaxation of load with respect to the applied load and time. From these data, the relaxation modulus, G, was calculated from the equation given below.

$$G = P/3\ A\ e_1,$$

in which: P = Applied Load
A = Area of Specimen (after straining)
e_1 = Strain (from original height of specimen)

The respective moduli for old and new wood are:

Old White Oak (From Cores)

50 lb. load:	G = 2398 psi	(60 Min)
100 lb. load:	G = 2856 psi	(164 Min)
150 lb. load:	G = 3834 psi	(110 Min)
200 lb. load:	G = 4668 psi	(75 Min)
250 lb. load:	G = 5596 psi	(360 Min)
300 lb. load:	G = 6348 psi	(70 Min)

New White Oak

58 lb. load:	G = 7145 psi	(62 Min)
100 lb. load:	G = 7903 psi	(60 Min)
150 lb. load:	G = 9371 psi	(60 Min)
200 lb. load:	G = 10,501 psi	(61 Min)
250 lb. load:	G = 11,572 psi	(68 Min)
300 lb. load:	G = 13,096 psi	(65 Min)

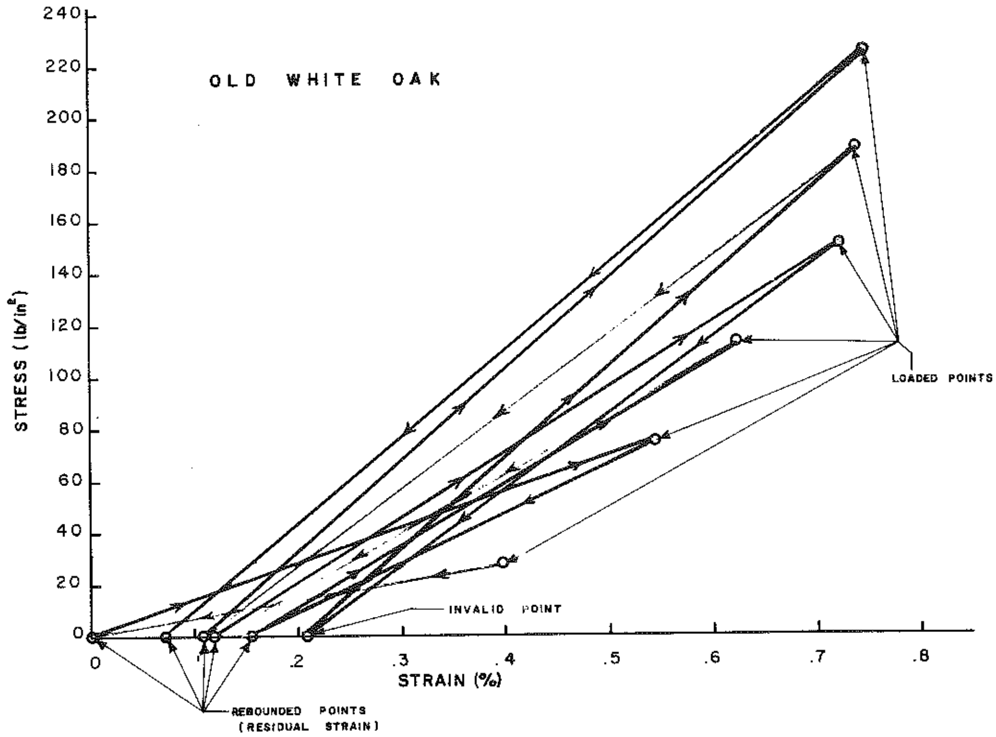
Finally, after a period of rest, the specimen was loaded at a constant rate of strain (1/1000 in. per min.) while monitoring the load. The resulting stress-strain graph is shown in Fig. 8. The effects of the previous strain history of the specimen is evident in the lower portion of the curve; some collapse of internal fibers undoubtedly occurred during previous loadings;

thereafter near-linearity is resumed. Also shown there is stress-strain curve obtained from successive, quick applications of 50-lb. increments of load (from Fig. 6).

Comparative compression graphs obtained from similar tests on a specimen of new white oak are provided for each of the test situations. Significant differences between the old wood and new wood are:

1. The old wood was kept wet except for slight drying while shaping the specimens; the new wood specimens were shaped and then soaked for five days.

2. The specimen of old wood contained 19 rings and 13 rays per inch; the new wood specimen contained 9 rings and 9 rays per inch.



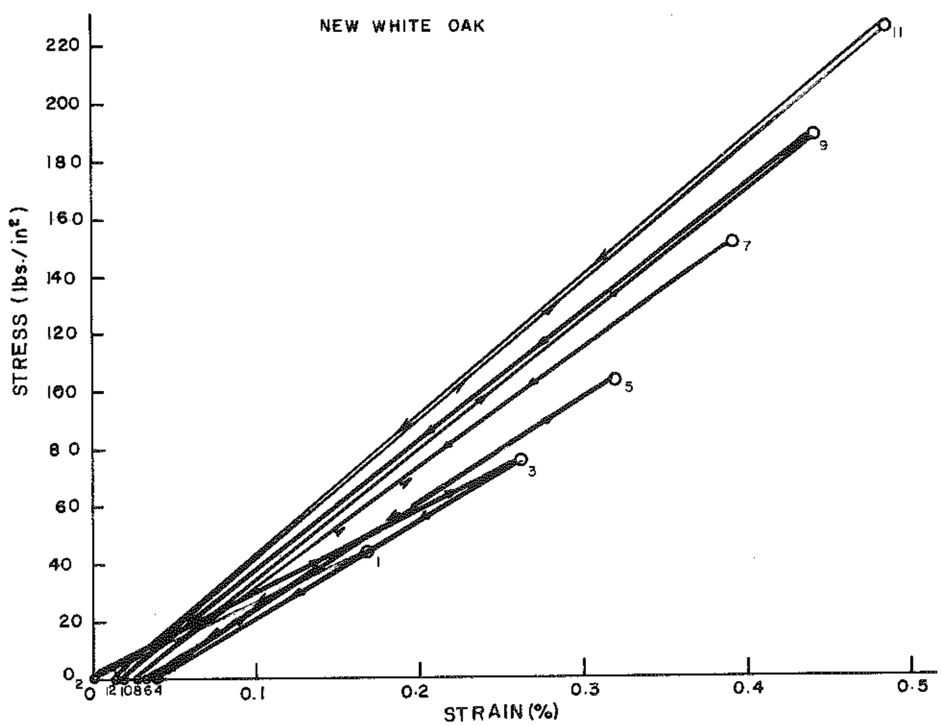
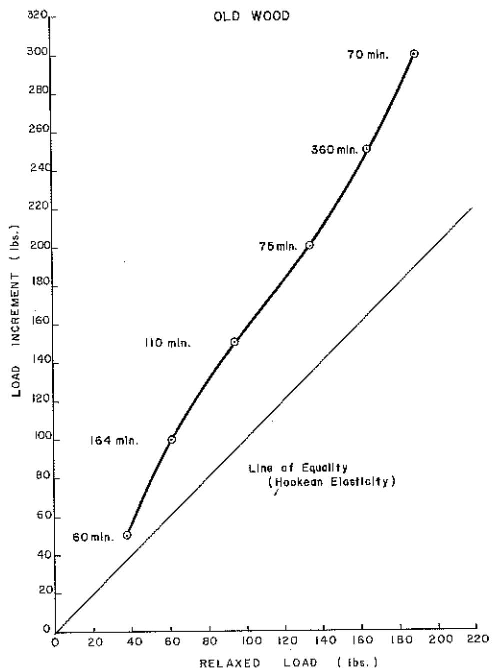


Fig. 6: Strain-Hysteresis Tests: Old and New Wood. Arrows show cycling of loads; points show total strains with respect to original height of specimen. Residual strain points show the unrecovered strains from each load-rebound cycle.



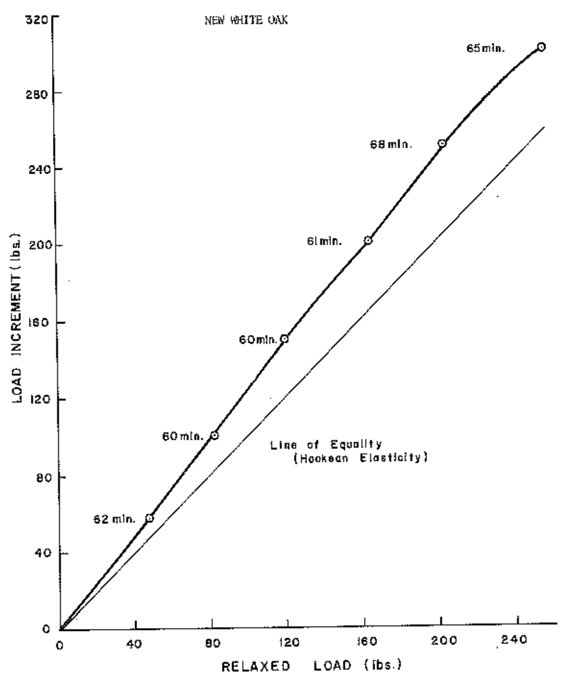
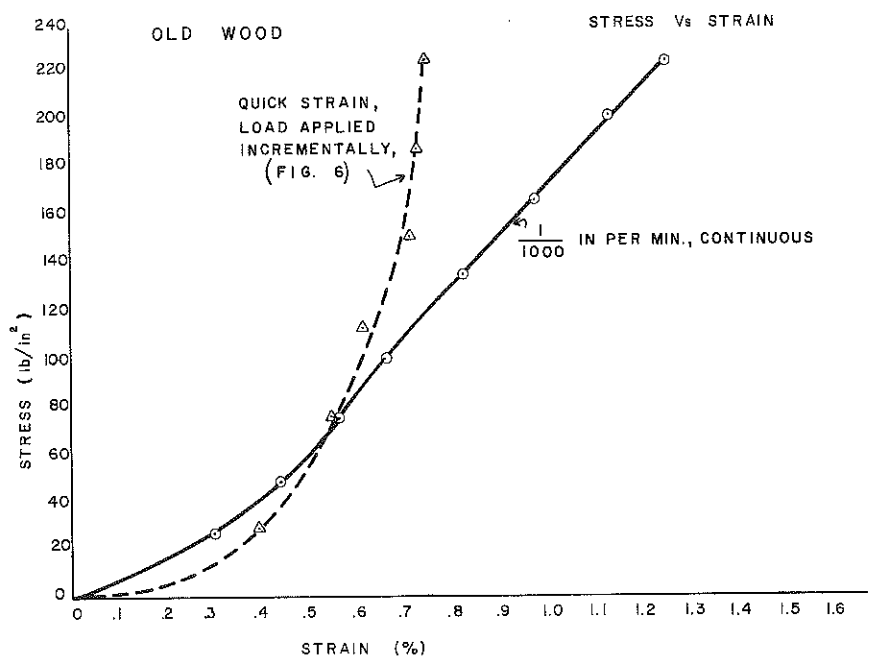


Fig. 7: Relaxation or Subsidence of Load - Due to Creep.



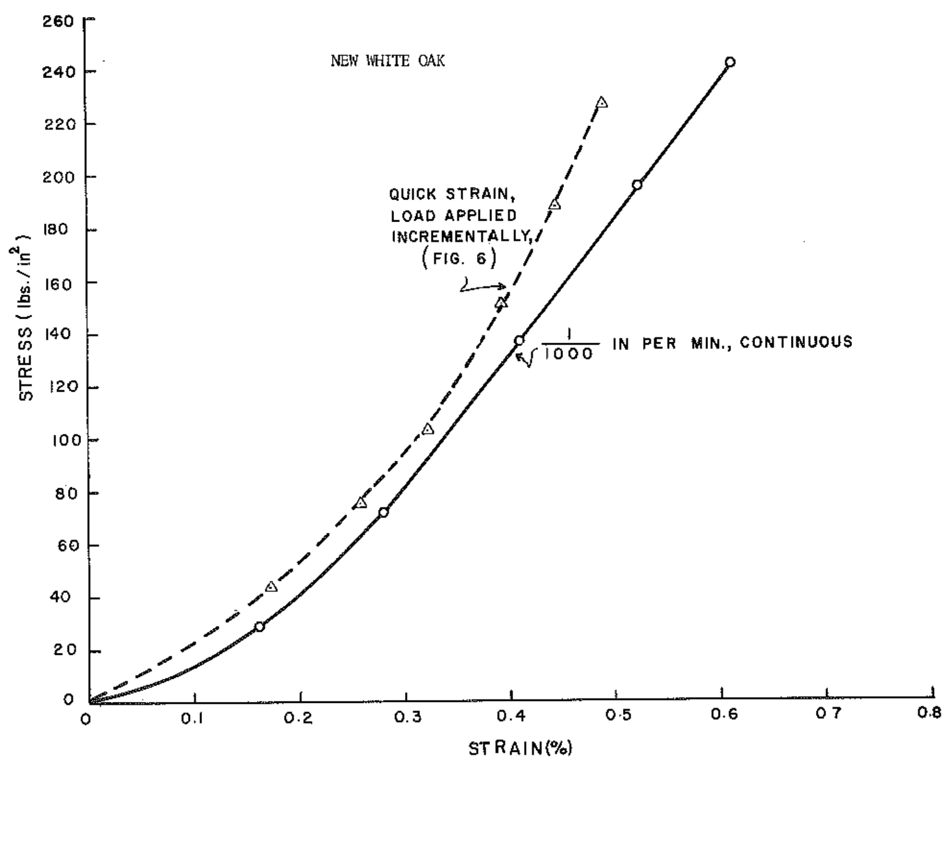


Fig. 8: Stress-Strain Curves Obtained in Triaxial Test Apparatus (20 psi lateral pressure) Following Creep-Relaxation Tests.

ANATOMY OF WOOD

The inner structure of white oak wood is similar to that of red oak, but white oak has perceptibly more abundant tyloses filling large spring-growth tracheid. Fig. 9 is a cross-sectional view of new wood (magnified 13.5 times). The parts are labeled. It is reportedly possible to blow air through the pores of a short length of red oak whereas the pores in white oak are plugged with tyloses. Tyloses are an intrusive growth of parenchyma cells into tracheid cells after sap flow subsides. Tracheid comprise the principal vertical (axial) piping system; they feed smaller, horizontal (radial) tracheid. These occur principally in the rays. The rays are discontinuous in the vertical direction and are an inch or more in height in white oak.

The porous springtime growth and the rays weaken the wood structurally. Strength is somewhat proportional to the amount of dense-wood (late growth) between the porous rings. Generally, the wider the rings the stronger the wood is (hardwoods only). In the dense-wood areas, the cells are smaller and have much thicker walls and are richer in intercellular resins (glues).

Fig. 10 is a companion to Fig. 9 and shows a side view of the same specimen.

Figs. 11 and 12 illustrate dark wood core specimens.

Fig. 13 is bright wood from Pier No. 2 and is comparative to Fig. 12.

Fig. 14 illustrates the pine in cross-section.

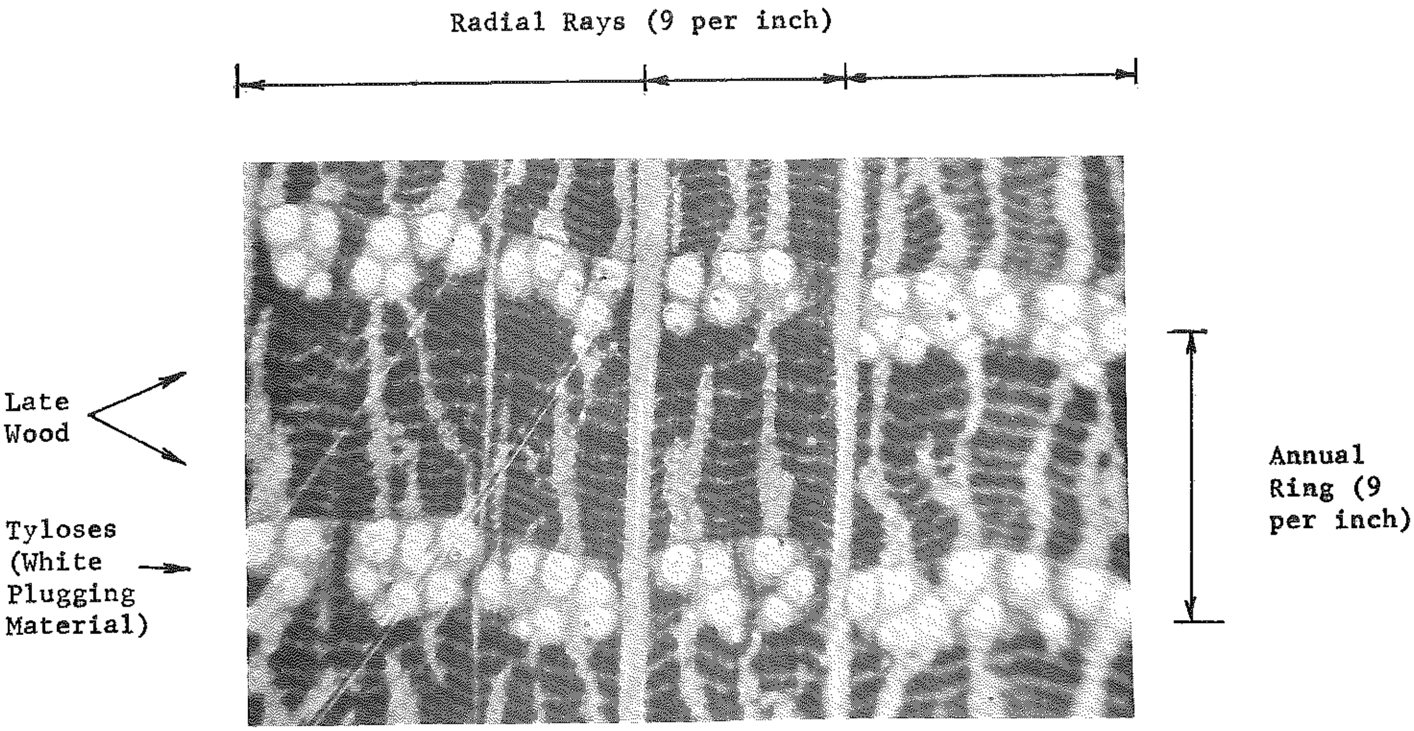


Fig. 9: Cross-Sectional View of New White Oak Magnified 13.5X.

1. Annual rings are large vertical pores (tracheid) produced by early spring growth; as growing season progresses additional pores form but become successively smaller and farther apart. The late wood growth is more dense and is stronger.

2. Radial rays are horizontal cells and lateral conductors of sap; they act as a lateral (radial) piping system. Rays are discontinuous in the vertical direction; each bundle is about one inch in height.

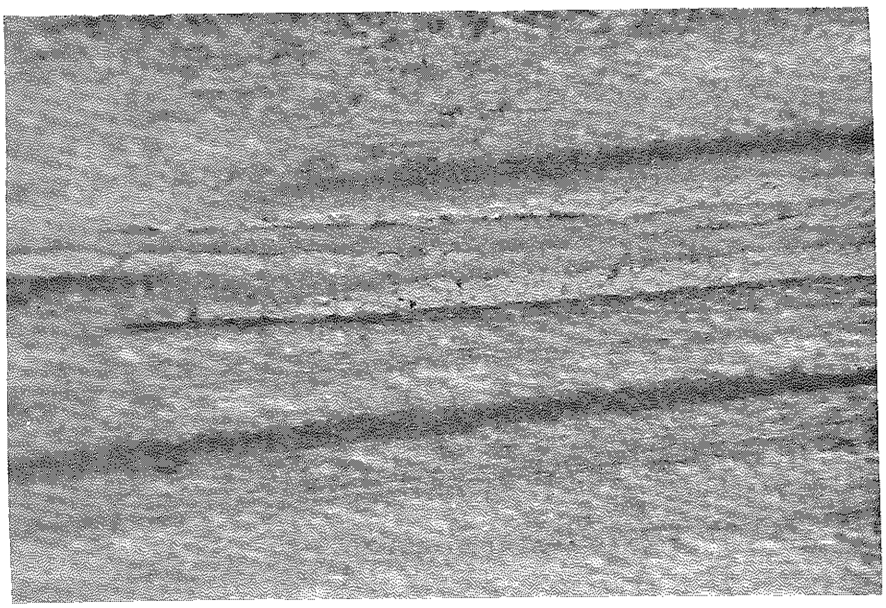


Fig. 10: Side View of New White Oak, Magnified 13.5X.

1. Tracheids, (Pores) filled with tyloses.

2. Ray; radial pores are not visible at this magnification.

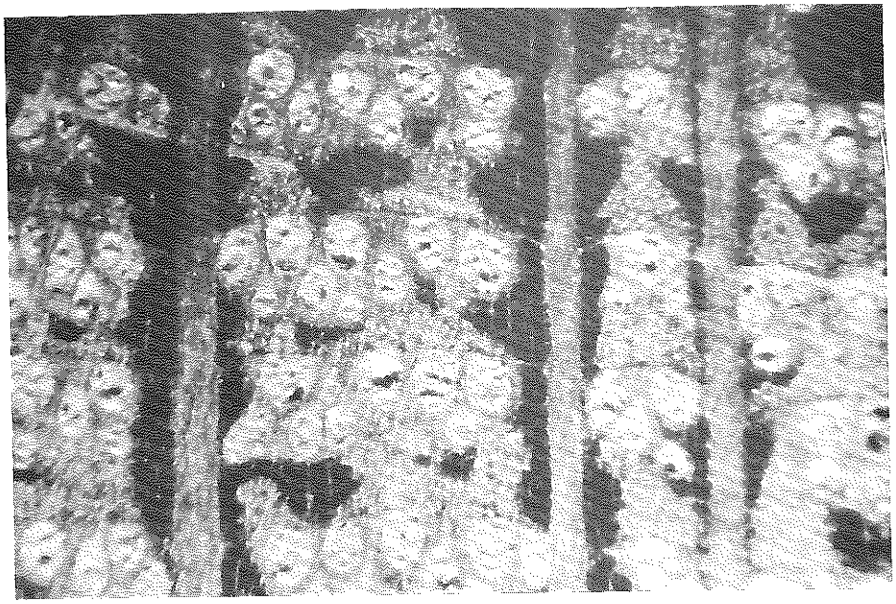


Fig. 11: Cross Sectional View of Dark Wood from Pier No. 2, Magnified 17.5X. Note greater abundance of large pores; specimen contains 17.5 rings per inch and 10 rays per inch.

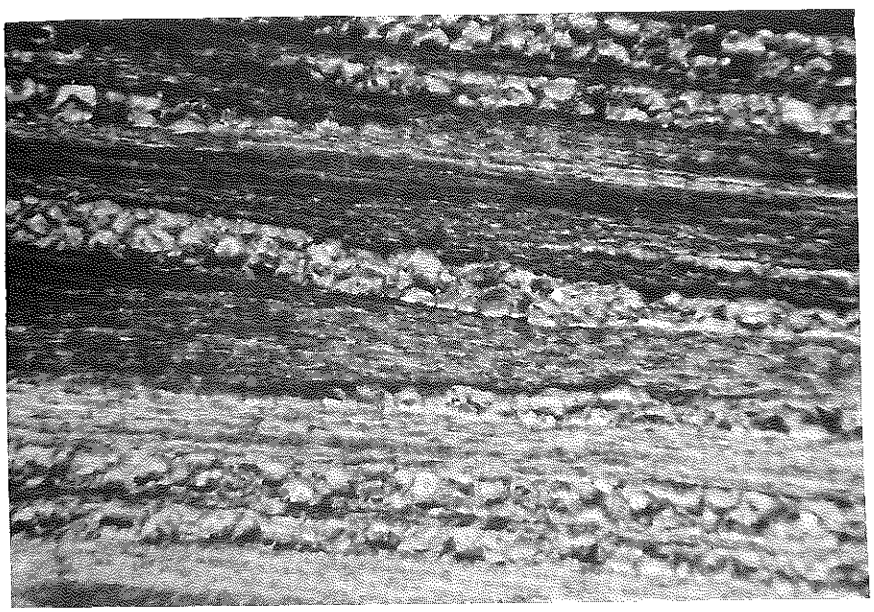


Fig. 12: Side View of Dark Wood from Pier No. 2, Magnified 17.5X. Greater abundance of large pores are evident here also.

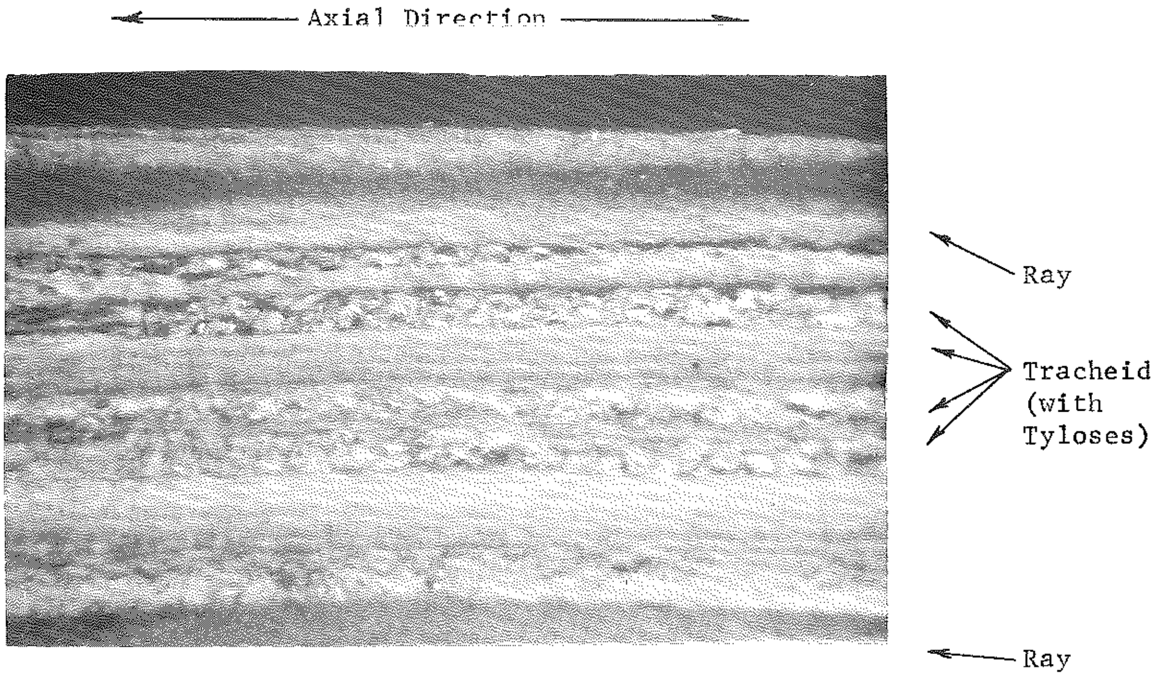


Fig. 13: Side View of Bright Wood from Pier No. 2, Magnified 17.5X.

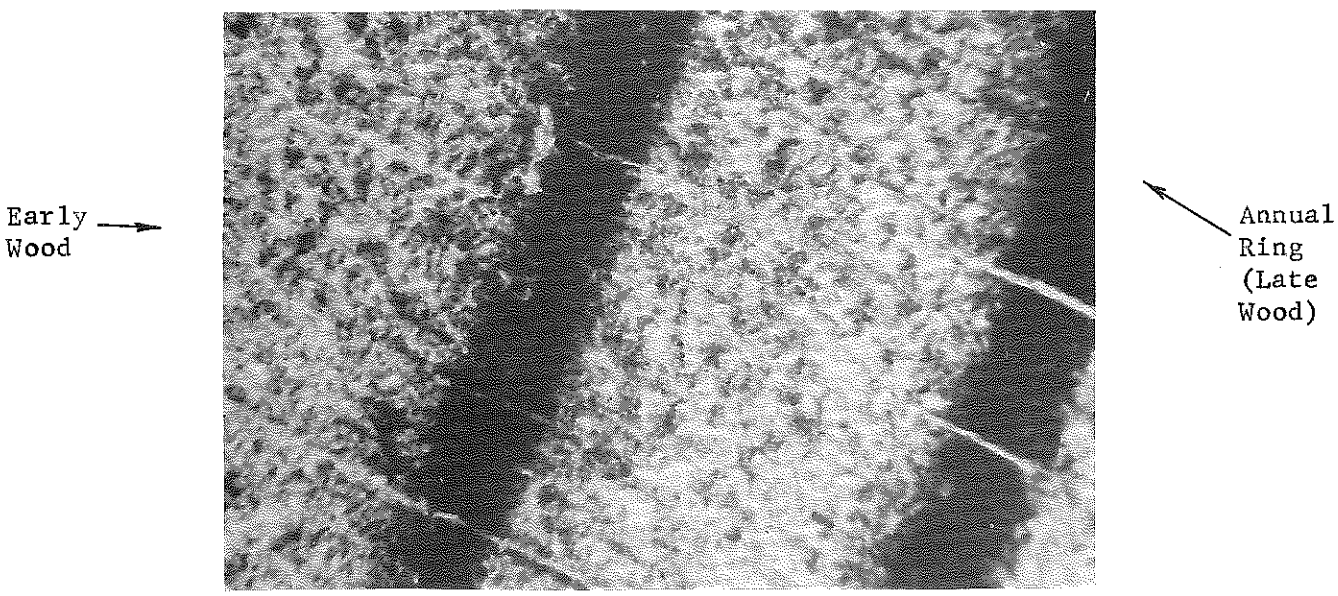


Fig. 14: Cross-Sectional View of Pine from Pier No. 2, Magnified 17.5X. In contrast to hardwoods, strength of conifer woods increases as the number of rings per inch increases.

DISCUSSION

The wood specimens tested were necessarily selected from portions within the cores which were recovered intact -- that is, showing the least internal damage (fraying, etc.) from the cutting bit. It should be recognized that there was not complete recovery; the possibility remains that the recovered portion of the cores, and thereby the specimens tested, represent only the best wood. This situation seems unreconcilable unless, through insight or conjecture, the imperfect recovery is attributed altogether to the coring equipment.

The only specimen of pine available in cores as received (specimens submitted to Forest Products Laboratory were selected from cores beforehand) contained a large knot and was not suitable for physical tests.

No specimens of yellow poplar was available. The tests were, therefore, limited to the white oak wood.

The simple compression tests and the relaxation moduli indicated an apparent loss of strength in comparison to new wood. If it were assumed that the old wood was originally as strong as the new wood, the differences in strength might be attributed directly to age, deterioration, decay, etc. However, there are significant reasons, based on anatomical or structural comparisons, to suspect that the new wood is superior to the original quality of the old wood and that interpretation of strength differences as a loss in strength of the old wood is not altogether justifiable. The old wood contains about twice as many porous rings per lineal inch as the new wood. Strength varies in some inverse proportion to the number of rings per inch -- probably more discretely with the percentage of the area occupied by large pores. Visual comparison of Fig. 9 with Fig. 11 suffices to show that the new wood and old wood are not identical in these dimensional attributes. A cursory ratio of 2:1 would, indeed, minimize the strength loss attributable to deterioration of the old wood -- that is, if wet-strength loss is used as an estimate or measure of deterioration. Air-dry strengths further minimize the extent of deterioration.

NOTE 1: In weighing these observations, attention should be directed also to Forest Products Laboratory's report and the discussions there concerning losses in acetyl content and the implied relationship between these chemical changes and strength.

On the basis of these observations, the loss in wet strength with time might be in the order of 25 percent -- part of which may be accountable in terms of saturation (cf. acetyl loss, FPL reports) and an undefined portion to bacterial decay (cf. FPL reports).

NOTE 2: The design bearing pressure was less than 100 psi (cf. Burr).

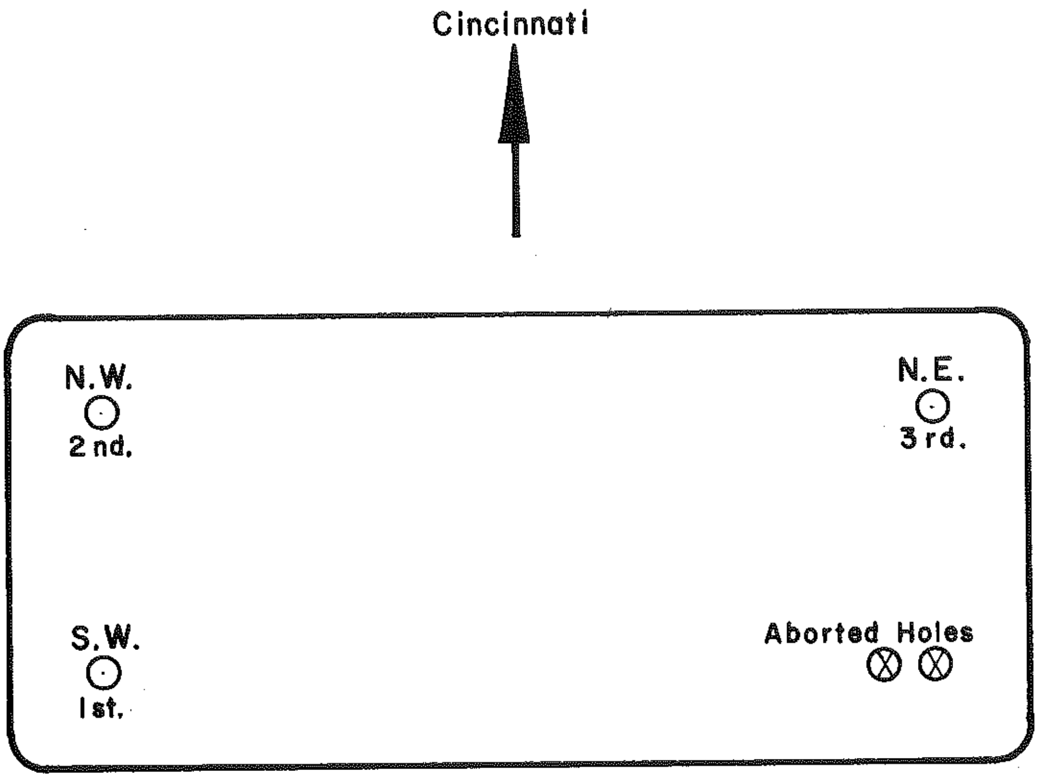
NOTE 3: There seems to be a noticeable degree of uncertainty implied in the FPL reports in regard to strength loss. "Inadvisable" was the word used in the FPL report of September 1970, to summarize all uncertainties bearing on re-use of the pier. In the earlier report, the term "not be depended on" was used. These same uncertainties appear in the FPL evaluation of pine piles under the 14th Street bridge in Washington, D.C. (see Item 3, Appendix II). The judgments rendered there were doubtlessly precedential.

The source of the white oak timbers is now unknown. Obviously, the new wood grew in an environment distinctly different from that where the old wood grew. It would be interesting to know if the old wood came from virgin forests in more northern climates or if the new wood specimen is merely typical of second-growth timbers.

APPENDIX I

A. LOCATION OF CORES

B. THE H.C. NUTTING COMPANY'S TEST BORING REPORTS



SCHEMATIC LOCATION OF CORE HOLES

Form No. 504—10-58

THE H. C. NUTTING COMPANY

TESTING ENGINEERS AND SOIL CONSULTANTS • SINCE 1921

4120 AIRPORT ROAD • CINCINNATI, OHIO 45226 • TEL. 513-321-5816

7-8-70 - kg

TEST BORING REPORT

CLIENT Hazelet & Erdal ORDER No. 1024.25

PROJECT Inv.of S.Pier of C&O R.R.& Cov.to Cinti. Hwy. Bridge HOLE No. S. W.

LOCATION Southwest quarter section of highway bridge pier

DRILLER W. Moore DRILL No. 25 DATE STARTED 6-24-70

ELEVATION REFERENCE Not given DATE COMPLETED 6-26-70

CASING: DIAMETER 3.5" I.D. HAMMER WT. FALL

SAMPLER: DIAMETER & TYPE 2" O.D. Split Spoon & NXM & BXM /Core Barrel HAMMER WT. FALL

DEPTH TO WATER: IMMEDIATE UPON COMPLETION

DEPTH TO WATER DAYS AFTER COMPLETION WATER USED IN DRILLING From 8.0'

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.	Recovery
	0'						
		0.2' Blacktop					
	0.2'						
		0.8' Concrete					
	1.0'						
		7.0' Void					
	8.0'			8-14.5	NXM	100%	
		6.5' Layered sandstone and concrete					
	14.5'			14.5-24.5	NXM	92%	
		10.0' Layered sandstone and concrete					
	24.5'			24.5-34.5	NXM	100%	
		10.0' Layered sandstone and concrete					
	34.5'			34.5-44.5	NXM	78%	
		10.0' Layered sandstone and concrete					
	44.5'			44.5-54.5	NXM	97%	

REMARKS:

Samples recovered from this test boring are available for inspection, which is strongly recommended. The company assumes no responsibility for interpretations made by others of load bearing, stability, excavating or other physical characteristics of materials penetrated in the boring.

Respectfully submitted,

THE H. C. NUTTING CO.

By C. Q. Kennedy

Form 504A—10-58

PROJECT Inv. of S. Pier of C&O R.R. & Cov. to Cinti. Hwy. Bridge HOLE No. S. W.

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.
	44.5'					
		10.0' Layered limestone and concrete				
	54.5'			54.5-64.5	NXM	100%
		10.0' Layered limestone and concrete				
	64.5'			64.5-74.5	NXM	98%
		10.0' Layered limestone, sandstone and concrete				
	74.5'			74.5-84.5	NXM	98%
		10.0' Layered limestone, sandstone and concrete				
	84.5'			84.5-94.5	NXM	100%
		10.0' Layered limestone, sandstone and concrete				
	94.5'			94.5-104.5	NXM	100%
		10.0' Layered limestone, sandstone and concrete				
	104.5'			104.5-114.5	NXM	100%
		10.0' Layered limestone, sandstone and concrete				
	114.5'			114.5-124.5	NXM	75%
		10.0' Concrete				
	124.5'			124.5-134.5	NXM	92%
		10.0' Concrete				
	134.5			134.5-139.5	NXM	50%
		5.0' Concrete				
	139.5'			139.5-149.5	NXM	100%
		10.0' Concrete				
	149.5'			149.5-151	NXM	
		1.5' Wood				
	151.0'			151-153	BXM	
		2.0' Wood				
	153.0'			153-155	BXM	

Form 504A—10-58

PROJECT Inv.of S.Pier of C&O R.R.& Cov.to Cinti.Hwy. Bridge HOLE No. S. W.

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.
	153.0					
		2.0' Wood				
	155.0			155-158	BXM	
		3.0' Wood				
	158.0			158-160	SS	90 H.B.
		2.0' Gray fine sand, moist - medium dense				
	160.0					
		Refusal at 160.0' on concrete				
		No water return				
		Wood samples retained by Hazelet and Erdal				
		BORING COMPLETED				

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7-8-70 - kg

TEST BORING REPORT

CLIENT: Hazelet & Erdal — ORDER No. 1024.25

PROJECT: Inv.of S.Pier of C&O R.R.& Cov.to Cinto.Hwy. Bridge — HOLE No. N.W.

LOCATION: Northwest quarter section of highway bridge pier

DRILLER: W. Moore — DRILL No. 25 — DATE STARTED 6-22-70

ELEVATION REFERENCE: Not given — DATE COMPLETED 6-26-70

CASING: DIAMETER 3.5"I.D. — HAMMER WT. — FALL

SAMPLER: DIAMETER & TYPE 2"O.D. Split Spoon & NXM & BXM /Core Barrel — HAMMER WT. — FALL

DEPTH TO WATER: IMMEDIATE — UPON COMPLETION

DEPTH TO WATER — DAYS AFTER COMPLETION — WATER USED IN DRILLING From 8.0'

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.	Recovery
	0'						
		0.4' Blacktop					
	0.4'	0.6' Concrete					
	1.0'	7.0' Void					
	8.0'	6.5' Layered sandstone and concrete		8-14.5	NXM	100%	
	14.5'	10.0' Layered sandstone and concrete		14.5-24.5	NXM	96%	
	24.5'	10.0' Layered sandstone and concrete		24.5-34.5	NXM	100%	
	34.5'	10.0' Layered sandstone and concrete		34.5-44.5	NXM	98%	
	44.5'			44.5-54.5	NXM	92%	

REMARKS:

Samples recovered from this test boring are available for inspection, which is strongly recommended. The company assumes no responsibility for interpretations made by others of load bearing, stability, excavating or other physical characteristics of materials penetrated in the boring.

Respectfully submitted,
THE H. C. NUTTING CO.
By [signature]

Form 504A—10-58

PROJECT Inv. of S. Pier of C&O R.R. & Cov. to Cinti. Hwy. Bridge HOLE No. N. W.

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.
	44.5'					
		10.0' Layered sandstone, limestone and concrete				
	54.5'			54.5-64.5	NXM	92%
		10.0' Layered sandstone and concrete				
	64.5'			64.5-74.5	NXM	96%
		10.0' Layered sandstone and concrete				
	74.5'			74.5-84.5	NXM	95%
		10.0' Layered sandstone and concrete				
	84.5'			84.5-94.5	NXM	98%
		10.0' Layered sandstone and concrete				
	94.5'			94.5-104.5	NXM	100%
		10.0' Layered sandstone and concrete				
	104.5'			104.5-114.5	NXM	75%
		10.0' Layered sandstone and concrete				
	114.5'			114.5-124.5	NXM	77%
		10.0' Concrete				
	124.5'			124.5-129.5	NXM	90%
		5.0' Concrete				
	129.5'			129.5-134.5	NXM	47%
		5.0' Concrete				
	134.5'			134.5-144.5	NXM	75%
		10.0' Concrete				
	144.5'			144.5-149.5	NXM	63%
		5.0' Concrete				Approx.
	149.5'			149.5-151	NXM	85
		1.5' Wood				
	151.0'			151-152.5	BXM	85
		1.5' Wood				
	152.5'			152.5-154.3	BXM	85

Form 504A—10-58

PROJECT Inv.of S.Pier of C&O R.R.& Cov.to Cinti.Hwy. Bridge HOLE No. N. W.

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.
	152.5'					
		1.8' Wood				Approx.
	154.3'			154.3-155.3	BXM	85
		1.0' Wood				
	155.3'			155.3-156.8	BXM	85
		1.5' Wood				
	156.8'			156.8-157.2	BXM	85
		0.4' Wood				
	157.2'			157.2-157.5	SS	180
		0.3' Concrete				
	157.5					
		Refusal at 157.5' on concrete				
		No Water Return				
		No Voids Noted				
		BORING COMPLETED				

Form No. 804—10-58

THE H. C. NUTTING COMPANY

TESTING ENGINEERS AND SOIL CONSULTANTS • SINCE 1921

4120 AIRPORT ROAD • CINCINNATI, OHIO 45226 • TEL. 513-321-5816

7-8-70 - kg

TEST BORING REPORT

CLIENT Hazelet & Erdal ORDER No. 1024.25

PROJECT Inv.of S.Pier of C&O R.R. Cov.to Cinti.Hwy. Bridge HOLE No. N. E.

LOCATION Northeast quarter section of highway bridge pier

DRILLER C. Casey & W. Moore DRILL No. 28 & 25 DATE STARTED 6-17-70

ELEVATION REFERENCE Not given DATE COMPLETED 6-28-70

CASING: DIAMETER 3.5"I.D. HAMMER WT. FALL

SAMPLER: DIAMETER & TYPE 2"O.D. Split Spoon & NXM & BXM /Core Barrel HAMMER WT. FALL

DEPTH TO WATER: IMMEDIATE UPON COMPLETION

DEPTH TO WATER DAYS AFTER COMPLETION WATER USED IN DRILLING From 8.0'

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.	Recovery
	0'						
		1.0' Blacktop and concrete					
	1.0'						
		7.0' Void					
	8.0'			8-17	NXM	94%	
		9.0' Layered limestone, sandstone and concrete					
	17.0'			17-25.5	NXM	59%	
		8.5' Layered limestone, sandstone and concrete					
	25.5'			25.5-30	NXM	100%	
		4.5' Layered sandstone and concrete					
	30.0'			30-35	NXM	100%	
		5.0' Layered sandstone and concrete					
	35.0'			35-40	NXM	80%	
		5.0' Layered sandstone and concrete					
	40.0'			40-45	NXM	100%	

REMARKS:

Samples recovered from this test boring are available for inspection, which is strongly recommended. The company assumes no responsibility for interpretations made by others of load bearing, stability, excavating or other physical characteristics of materials penetrated in the boring.

Respectfully submitted,

THE H. C. NUTTING CO.

By

Form 504A—10-58

PROJECT Inv.of S.Pier of C&O R.R.& Cov.to Cinti.Hwy.Bridge HOLE No. N. E.

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.
	40.0'					
		5.0' Layered sandstone and concrete				
	45.0'			45-50	NXM	100%
		5.0' Layered sandstone and concrete				
	50.0'			50-55	NXM	100%
		5.0' Layered sandstone and concrete				
	55.0'			55-60	NXM	100%
		5.0' Layered sandstone and concrete				
	60.0'			60-65	NXM	100%
		5.0' Layered sandstone and concrete				
	65.0'			65-72	NXM	100%
		7.0' Layered sandstone and concrete				
	72.0'			72-82	NXM	97%
		10.0' Layered sandstone and concrete				
	82.0'			82-92	NXM	87%
		10.0' Layered sandstone and concrete				
	92.0'			92-100	NXM	93%
		8.0' Layered sandstone and concrete				
	100.0			100-107	NXM	100%
		7.0' Layered sandstone and concrete				
	107.0			107-117	NXM	94%
		10.0' Layered sandstone and concrete				
	117.0			117-127	NXM	35%
		10.0' Concrete				
	127.0			127-134	NXM	36%
		7.0' Concrete				
	134.0			134-142	NXM	25%

Form 504A—10-58

PROJECT Inv.of S.Pier of C&O R.R.& Cov. to Cinti.Hwy. Bridge HOLE No. N. E.

ELEVATION	DEPTH	DESCRIPTION OF MATERIALS	SAMPLE No.	SAMPLE DEPTH	TYPE OF SAMPLE	BLOWS PER 6" ON SAMPLER or % Core Rec.
	134.0'					
		8.0' Concrete				
	142.0'			142-149	NXM	0
		7.0' Concrete				Approx.
	149.0'			149-150	BXM	68
		1.0' Wood				
	150.0'			150-152	BXM	68
		1.0' Wood				
	151.0'					
		1.0' Wood				
	152.0'			152-154	BXM	68
		2.0' Wood				
	154.0'			154-156	BXM	68
		2.0' Wood				
	156.0'			156-157.3	BXM	68
		1.3' Wood				
	157.3'			157.3-157.5	SS	130
		0.2' Concrete				
	157.5'					
		Refusal at 157.5' on concrete				
		No water return				
		No voids noted				
		BORING COMPLETED				

APPENDIX II

REPORTS OF FOREST PRODUCTS LABORATORY

1. September 1970

2. Rec'd May 21, 1970

3. 14th Street Bridge over Potomac River, Washington, D.C.; Wood Preserving, AWPI, January 1970.

REPORT OF CONDITIONS FOUND IN ADDITIONAL SAMPLES TAKEN IN JUNE 1970 FROM THE PIER-SUPPORTING GRILLAGE OF THE U.S. 25 HIGHWAY-RAILROAD BRIDGE BETWEEN COVINGTON AND CINCINNATI

By

JOE W. CLARK

Forest Products Laboratory,[1] Forest Service
U.S. Department of Agriculture

Introduction and Background

This supplemental report has been prepared to become a part of the earlier report submitted in May 1970. That report was based on sample cores taken in January 1970 and obtained from a single hole bored through the grillage timbers. This supplemental appraisal has been made on sample cores obtained in June 1970 from two additional borings through the grillage members. The June samples were frozen and held in cold storage, including refrigerated (dry ice) packaging, for shipment to the Lab prior to examination in contrast to alcohol pickling which was used with the January samples. As indicated in the May report, there was a question of sample adequacy using only the January cores taken from a single hole through the grillage. The cores taken from the two additional holes in June have largely confirmed the earlier findings and have provided some additional information.

---

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Wood Species Present in the Grillage and the Pattern of Distribution

For the three sets of cores obtained from as many holes, the pattern of wood species distribution has been the same. This includes an upper (first) member of yellow-poplar, a lower (seventh) member of southern yellow pine, and the intervening five members (of the materials examined) having been oak. Practically all of the oak examined has been white oak heartwood. Some of the interior grillage timber samples were not represented by the materials received for examination at FPL.

Species distribution in the grillage mass is of very considerable significance since the placement of the yellow-poplar timber as the uppermost member leaves it exposed to the alkaline environment adjacent to the poured concrete, which results in a partial but highly significant loss of wet strength. The lower member being pine, also in contact with concrete, is not so severely affected since coniferous species are less affected by equivalent alkaline conditions in comparison to hardwoods. One must assume from the three samples examined that there is a single layer of yellow-poplar timbers making up the uppermost layer of the grillage.

Atypically Weakened Wood, Macroscopically Evident

In the January sample, the uppermost grillage member (yellow-poplar) was very noticeably weakened and, in the wet condition, could be characterized as "mushy" or "spongy." This was attributed to chemical degradation related to the members having been a hardwood in strongly alkaline environment. Loss of acetyl was used as a measure of the extent of such weakening. Both yellow-poplar samples from the two sets of cores taken in June showed a similar characteristic loss of acetyl and this presumably was again attributable to the prolonged contacting exposure of the upper member to the poured-in-place concrete.

In the June-collected set of samples the second grillage timber from the top in hole NE at elevation depth 150 feet was a distinctly softened oak member that was classified as punky in the wet condition. The sample pieces of this timber in the wet condition offered little resistance to sawing or cutting with a knife. It is probably significant that this member was next to the top timber in the array of seven timbers and therefore in relatively close proximity to and below the poured concrete. The small samples of this member checked severely on drying, which is a further indication of severe deterioration.

Microscopic Appraisal of Samples

Microscopically, the array of June-collected core samples was very similar to the January cores previously examined. The commonly noted presence of bacteria in practically all of the tissues examined was characteristic of the samples including all three species of wood and unquestionably permeating the white oak heartwood.

Bacteria were unusually abundant in the oak sample cited above where they were literally impacted in all types of cells comprising both the longitudinal and horizontal tissues. It is probable that the severe weakening of this member was caused, at least in part, by the bacteria present.

In both pine samples received with the June cores, the same break-down of secondary tracheid walls in the cells representing terminal growth for the respective annual rings was observed as indicated in the earlier report and illustrated by figures 4 and 5 of that report. Again, no fungi were detected microscopically in these areas and the wall failures are thought to result from bacterial attack.

Culture Isolations

The June samples were received in a frozen condition, wrapped in plastic, and packaged in dry ice. This method of handling the cores made successful cultural isolations possible and a much larger array of organisms have been isolated than was obtained from the alcohol-pickled samples taken in January. The cultured isolates represent various forms of micro-organisms, including several species of both coccus and rod forms of bacteria, yeastlike organisms, and actinomycetes. None of these organisms have been specifically identified, but such identities are not essential to the practical appraisal of the present problem. That the organisms are living in the grillage wood, are present in all species of the grillage timbers including the oak heartwood, and represent a large variety of micro-organisms make this aspect of the grillage condition questionable as regards its prolonged future service.

Acetyl Loss in Representative Samples

Acetyl loss, as determined by the Division of Wood Chemistry, was very similar for the last received (June) samples as for the former samples (collected in January). Loss in the yellow-poplar samples was from one-third to three-quarters of the estimated acetyl formerly present. It is also estimated that roughly one-half of the acetyl had been lost from the oak samples. Acetyl losses in the pine samples were again quite minimal.

Individual sample appraisals for acetyl loss are shown in the following table, along with other sample data.

Data for Grillage Samples Collected in June 1970

Sample	Rings per inch	Wood species	Specific gravity[1]	Acetyl present[2]
NE 149(A)	12	Yellow-poplar	0.426	0.81
NE 150(A)	17	White oak	.449	1.50
NE 156(D)	26	........do......	[3].758	1.86
NE 156(E)	20	Yellow pine	.453	.85
NW 149.5(A)	26	Yellow-poplar	.320	1.19
NW 149.5(B)	26	White oak	.583	1.43
NW 156.3(D)	16	........do......	.379	1.95
NW 156.8(B)	24	Yellow pine	.440	1.06

[1] The specific gravity averages or ranges normally to be expected for the three species are as follow: yellow-poplar -- 0.38; white oak -- 0.55-0.64; and southern yellow pine -- 0.45-0.64.

[2] Hardwoods normally have an acetyl content of from 3 to 5 percent; while coniferous species have much less.

[3] This sample showing an abnormally high specific gravity was ashed and found to contain an above-average content of deposited mineral matter.

These levels of acetyl loss indicate a very definite loss of wet strength in the most severely affected piece of yellow-poplar examined and could result in compression failures if a comparable degree of weakening becomes uniform across the bearing face of the grillage. Wet strength losses in the oak members have been definite but not hazardous usually; however, they could possibly become critical if additional acetyl loss occurs or if strength loss develops generally as a result of the activity of the micro-organisms, which are abundantly present.

Recommendations

In view of the present findings which are essentially similar to the findings reported in our earlier written report, it would appear inadvisable to rebuild the new bridge on the old grillage-supported pier with the expectation that 80 to 100 years of service life will be assured. Alternatively, we cannot say with certainty that the grillage will not continue to support the pier adequately for that length of time; but because there has been a very considerable amount of chemical degrade, which may be continuing slowly, and because organisms are still present, which may biologically affect the service life of the structure, it would seem appropriate to rebuild the bridge using a design that would permit, if necessary, the addition of a supporting pier as outlined in our earlier conversations with Mr. Wood and again with Mr. Grayson.

CONDITION OF THE PIER-SUPPORTING WOOD GRILLAGE OF THE U.S. 25 HIGHWAY-RAILROAD BRIDGE OVER THE OHIO RIVER BETWEEN COVINGTON AND CINCINNATI

By

JOE W. CLARK, Pathologist

Forest Products Laboratory,[1] Forest Service
U.S. Department of Agriculture

An earlier, verbal report was made to Mr. Robert H. Wood on March 12, 1970, covering the initial results obtained in an appraisal of cored wood samples of the timber grillage received from the Hazelet and Erdal Company of Louisville, Ky. These samples were obtained from in-place coring of the grillage under the south river pier of the U.S. 25 bridge over the Ohio River between Covington and Cincinnati. This large concrete and masonry pier extends 142 feet above the grillage on which it rests, and the grillage occupies an area 79 by 34 feet and is composed in depth of seven layers of 12- by 12-inch timbers. The upper surface of this solid-piled mass of timber is at a point approximately 40 feet below the river surface (water) level and 30 feet below river bottom. The grillage material has been in place since 1890 when the bridge was built. Following is the final report giving a full account of our completed appraisal of the samples and including results from additional tests not completed or reported at the time of our last verbal communication with Mr. Wood.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Physical Damage to the Samples by the Core-Boring Process

The core samples received at the Laboratory for appraisal had been subjected to variable degrees of twisting attributable to the core cutting or boring process. This twisting action. in some core segments, caused much fiber breakage or separation, particularly in the outer 1/4 to 3/8 inch of the core samples. In some cases, such damage extended completely through the core, while in other cases the damage was superficial, limited to the core surface, and considered negligible. The occurrence of such damage appears to have resulted during the boring process from the random packing of the kerf material between the in-place core and the inside surface of the core cutting tool as it revolved. Most of the core samples were firmly encased in such wood fiber compactions when received at the Laboratory. The subsequent sample appraisals were based exclusively on the interior parts of the core samples which were free from visually detectable twisting deformation.

Microscopic Examination of the Sample Material

Microscope slides were prepared from material taken at different levels in the grillage. From these slides positive identifications of wood samples were made by Dr. Kukachka, the senior wood taxonomist at the Laboratory. Of the 11 core fragments examined, nine were white oak, one was yellow-poplar, and only one was yellow pine, although the original account of the construction indicated that the grillage was constructed of pine timbers.

Careful appraisal of the material prepared for microscopic examination showed bacteria commonly present in all samples (see fig. 1). Assigning specific cell-wall deterioration in the wood to these organisms has not been possible, although some instances of biological degrade of the wood were noted in the pine sample (see figs. 4 and 5). This type of damage was observed to be present in varying degrees in the latewood cells of most annual rings in the pine that was inspected. Such degrade could be particularly significant in strength loss if generally present in extensive areas of the grillage members. No filamentous fungi were detectable in association with this degrade, but more sampling will be necessary before a reliable appraisal of the pine present in the grillage can be made.

All of the bacteria observed microscopically in the wood sample sections appeared to be coccus forms. All 32 cultured isolates obtained from the randomly sampled grillage cores are rod forms of bacteria (see fig. 2). This suggests that the alcohol solution used for protecting the cores may have killed the coccus forms, observed microscopically, and permitted the culture recovery of only a comparatively resistant or spore-forming rod form.

Generally, bacteria are thought to cause little deterioration of the wood cell wall material but rather to utilize cell contents and certain pit membranes causing some increase in porosity but little strength loss. The effects of many bacteria on wood are incompletely known.

In a few cases the hyphae of unidentified fungi were observed in oak members, but these were not profusely developed and may represent dead fungus infections that were established in the freshly cut timber or during construction and prior to the covering of the grillage with the resulting exclusion of air from the material. No fungi were obtained in culture, although they too may have been killed by the alcohol pickling solution if any were living.

Ruptures in the cell walls representing compression failures (fig. 3) were rather common, but it was impossible to establish the exact cause of such defects. Possibly, these failures could have resulted from the twisting action of the core-boring process referred to above. Also, longitudinal separation of the wood cells along the primary walls was observed at infrequent points. This, too, could have resulted from the same cause, although material was selected for slide preparation that was free of visibly apparent defects thought to have been induced by the coring process. Alternatively, bacteria, actinomycetes, or soft-rot fungi, capable of preferentially attacking lignin, could possibly account for abnormal weakening of the primary wall and consequent failure under torque loading since the primary wall is predominantly lignin.

Chemical Depositions in the Wood

Portions of the yellow-poplar sample appeared to be crusty and microscopic inspection of such parts showed a crystalline chemical deposition in the wood cells to a depth of 1/2 inch or slightly more measured from what appeared to be an upper or lower surface face of the timber. Two different forms of the deposition were noted; one, a yellowish crystal material, was represented by particles several times the diameter of the largest wood cells. Such crystal accretion in the wood disrupts the cellular structure of the wood and causes very acute localized loss of strength. Fortunately, such accretions were only observed in the single sample of yellow-poplar.

A second form of chemical deposition or accretion appeared as a white crystalline material filling cell lumens in the same general area as the yellowish crystal material noted above. This deposition was also present in the yellow-poplar only and since this timber represented the uppermost piece of the grillage, it would presumably have been in contact or approximately in contact with concrete which was poured over the grillage. Tests indicated that at least one of the chemicals is likely to be calcium carbonate.

Specific Gravity Determinations

Specific gravity of the several samples was determined on the basis of green volume (water displacement) and ovendry weight. The samples tested were approximate cubes cut from the center of solid wood segments of the cores. The cubes were generally from 0.5 to 0.7 inch on a side. The footage depths at which the core segments were taken served as identifying numbers for the cubes used in the specific gravity determinations; and the results of these tests gave the following values:

Sample No.	Sample wood species	Rings per inch	Sample specific gravity[1]	Average or range of specific gravity for the species
149.0	Yellow-poplar	32	[2]0.45	0.38
151.5	White oak	13	.69	0.55-0.64
152.0	.....do.......	16	.62	.55- .64
152.5	.....do.......	12	.61	.55- .64
155.5	.....do.......	13	.60	.55- .64
156.0	.....do.......	14	.64	.55- .64
156.5	Southern pine	28	.43	.45- .64

[1]Specific gravity determinations were made with the help of Harold Wahlgren in the Division of Wood Quality Research, using the specialized equipment in that Division developed for the purpose of gravity determinations.

[2]This value is possibly high due to probable calcium carbonate deposition.

Acetyl Content Determination

During a conference with Dr. Harold Tarkow, Chief of the Wood Chemistry Division at the Laboratory, he suggested that the wood grillage, submerged as this material has been in an alkaline environment, resulting from the curing of the concrete, could possibly have been adversely affected by chemical changes in this period of time. The occurrence and extent of such a change is best estimated by measuring the loss of acetyl which can be used as an indicator of the change. Wood material varies in this reaction, depending on the species of the wood, the specific character of the liquid environment as to the chemicals present and the prevailing pH, and the length of time of exposure. These chemical changes are somewhat similar to those induced by the cold soda pulping process used in the conversion of hardwood species. Generally, the hardwoods are affected in a shorter period of time and more severely than softwoods under comparable conditions, as shown in the following table:

Wood species and sample No.	Acetyl content (Pct.)
White oak No. 152.0	1.82
White oak No. 155.5	1.77
White oak No. 156.0	1.73
Yellow-poplar No. 1.49.0	.38
Yellow pine No. 156.5	.89

Hardwoods commonly contain 3-5 percent acetyl while conifers normally contain much less. Thus, the results indicate a loss of acetyl in the oak samples of more than 50 percent of what is estimated to have been present originally. The pine sample showed little loss of acetyl, having originally contained an estimated 0.6 to 1.0 percent. The yellow-poplar had lost perhaps as much as 75 percent of the acetyl estimated to have been present originally, and thus appears to have been seriously and critically weakened.

The significance of this loss is not the absence of the acetyl, but rather the resulting effect of the total chemical change, of which the acetyl loss is only a part. This effect can be demonstrated by treating wood with dilute alkali to cause elevated fiber saturation levels. Fiber saturation in hardwoods may be as high as 65 or 70 percent moisture content. This characteristic of wood has been demonstrated and reported by Tarkow and Feist; a copy of the report is attached and attention is directed to table V, page 82, and the section "Effect of Treatment with Dilute Alkali," pages 82 and 83. Additional work by W. Klauditz (1957), has shown that wet strength losses as high as 50 percent may result from very short treatments of mild solutions of dilute alkali. Highly significant reductions in <u>all strength properties</u> are known to be characteristic of wood at such high fiber saturation levels.

The fact that dry wood strength is much less affected by these changes is of little consequence in this case since the grillage members undoubtedly remain water saturated in their present position. Inasmuch as these strength losses are of significance primarily in the hardwoods, such as the white oak and yellow-poplar in contrast to the pine of the grillage samples, additional sampling of the grillage is highly desirable to determine what wood species are actually present and how the different species are distributed.

Additional corroborative evidence of strength loss in the yellow-poplar core sample was its "mushy" character, evident in the saturated condition by moderate finger pressure in contrast to a near-normal wood firmness in the dry condition. Further, it may be noted that the yellow-poplar sample had to be frozen to obtain sufficient rigidity, in the wet condition, to cut thin sections for microscope examination, while none of the other samples required similar support.

Summary of Findings

The several characteristics determined for the grillage samples can be summarized as follows:

(1) Severe twisting of the core samples attributable to the coring process caused much physical damage in varying amounts to the core wood. In our appraisal of the cores, we attempted to avoid such damaged material. There is a definite chance that some of the coring damage may have resulted from the weakened physical condition of the wood, representing a loss of strength due to chemical and/or biological deterioration. This is very definitely true for the single sample of yellow-poplar. In the samples of oak and in the one pine sample, some part of the physical damage during coring may have resulted from chemical or biological weakening, from random compaction of kerfed fibers and particles, or from a combination of these two factors.

(2) Identification of core samples showed the predominant wood species to be white oak rather than pine as reported in the original account of the construction. One segment of yellow pine was included in the samples as well as a segment of yellow-poplar.

(3) Bacteria of both coccus and rod forms were present in the core samples as determined either microscopically or by cultural isolation. It was not determined whether the culture isolates were capable of lignin

or cellulose degradation, but definite degrade of the secondary cell walls of the pine sample was observed. Although no fungus hyphae were found associated with this specific degrade, it is suggested that this is an example of biological degradation. This type of biological attack was repeatedly observed in the latewood cells of the pine sample annual rings. Whether this degradation had occurred prior to, during, or after bridge construction could not be determined, but it must be considered significant evidence of strength loss.

(4) Fungi were observed microscopically in several instances in the oak samples. No fungi were obtained in 30 culture isolation attempts and it seems probable that the observed hyphae were the result of infections having started prior to or during the construction period. Very little deterioration of wood cell-wall material was associated with these fungi in the material examined.

(5) Rupture of a compression-failure type in the secondary wall of some wood cells was moderately common and separation of adjacent rows of oak fibers along the primary wall was also observed in several samples Whether these forms of damage were due to biologically or chemically degraded wood or to the mechanical stresses imposed by core boring was not determinable.

(6) Specific gravity determinations for seven samples, including one pine, one yellow-poplar, and five oak members, showed no abnormally low-density material, although the pine sample was just below the minimum specific gravity for the range of yellow pine. The wood samples were approximately normal for rates of growth: Oak showed 12-16 rings per inch pine showed 28 rings per inch (a reasonably slow growth for this species),

and yellow-poplar showed 32 rings per inch (a decidedly slower rate or growth than normal).

(7) A test for chemical changes indicated by acetyl loss in the samples was positive for the hardwoods, but only extensive enough in the yellow-poplar sample to be definitely considered hazardously weakening. Appraising this factor is particularly difficult since there is no way of determining how much more weakening will develop in the future. Normally, under stable conditions, acetyl loss occurs more rapidly in an initial period and becomes less rapid due to a reduced rate of loss after a prolonged period.

If the additional cores to be taken in the future prove to be largely pine, this specific problem would be considered less significant than it now appears to be.

Conclusions and Recommendations Suggested for Consideration

As a general summary, it should be noted that no single factor or combination of factors that have been appraised point to a definite and unequivocal condemnation of the grillage for continued support of the pier as proposed in the reconstruction of this bridge. However, the marginal character of some factors, the unpredictable degree by which some of these factors may change in the future, and the remaining unknown entities due to sample limitations that fail to provide sufficient information on the species of wood present, and their distribution in the grillage assembly are ample justification for a recommendation that the grillage not be depended on for complete support of the pier through the service life of the anticipated bridge reconstruction.

Principal considerations leading to this conclusion include the following:

(1) The sample is inadequate for a broad and reliable conclusion, coming as it does from a single set of cores taken from a single hole in a very considerable expanse of timbers that we must now assume are composed of at least three species and possibly more. Further, the core-cutting process has introduced a degree of twisting and breakage in the samples that has been difficult to appraise.

(2) Substantial and critical strength loss has occurred in the upper yellow-poplar grillage member as a result of chemical changes, presumably induced by an alkaline environment associated with the overlying concrete. Without extensive additional sampling to identify wood species and their distribution, the significance of this factor cannot be accurately appraised.

(3) Additional strength loss has also occurred in the oak samples from the same cause, but the extent of strength loss is considered marginal. We cannot predict with surety whether or not further significant chemical change in the oak will occur in the next 80 years.

(4) Biological degradation in some segments of the core samples now approach a marginal point in strength loss. Much depends on how extensive or common such areas may be and whether living organisms are still active. This can only be estimated with additional sampling and culturing.

(5) The probability of additional degradation by either chemical or biological agents with time cannot be predicted with a high degree of certainty. However, assuming no change in the environment surrounding the grillage, it is possible that little additional deterioration will occur.

Recommendations

(1) We recommend that numerous additional cores be taken with an improved coring tool to better appraise the species of wood present, their distribution, and their physical and biological condition.

(2) Special attention should be given the uppermost and lowest grillage members which contact concrete and particularly so if these members are hardwoods.

(3) Special consideration should be given in appraising any yellow-poplar members present as to the amounts found and their location or distribution.

Suggestions for a Preservative Application and the Filling of Voids

If the engineers decide to continue the grillage in service and to pressure-fill holes bored on a grid pattern, as previously considered, to eliminate any voids that may now be present above or below the grillage, it would then be our recommendation that, after the holes are drilled and before the consolidating fill is applied, a water-soluble, toxic agent, such as the wood preservative FCAP, be forced under pressure into the grillage interfaces and any other available space. This material is a recognized wood preservative containing fluoride, chromium, arsenic, and dinitrophenol. Such material would presumably, by slow diffusion over an extended period of time, permeate much of the grillage wood and retard further biological deterioration in the treated portions.

This specific toxicant has been recommended by Lee Gjovik of the Wood Preservation section. The material would be available from either the Koppers Company, Inc., or from the Osmose Wood Preserving Company.

For further information about this product, we suggest that you contact, respectively, either:

Mr. R. B. Putman, Manager
Wolman Preservative Department
Forest Products Division
Koppers Company, Inc.
Koppers Building
Pittsburgh, Pennsylvania 15219

Mr. George B. Fahlstrom, Director
Research Division
Osmose Wood Preserving Co. of America, Inc.
980 Ellicott Street
Buffalo, New York 14209

Either of these men may have specific advice that could be useful to you. Also, you should be advised that this preservative has been classified as a pesticide under current pesticide regulations. It is recommended, therefore, that the appropriate state agencies be consulted before the material is used.

Finally, we would recommend that a fill material having a slightly acid or netural pH be used to eliminate the grillage voids. The addition of more alkaline material could likely cause additional chemical changes indicated by loss of acetyl which may otherwise be stabilized at this point.

Figure 1.--Bacteria supported on tylosal membranes in vessel cells of white oak samples. This particular slide was prepared from oak core sample taken at the 152.0-foot level, but such bacterial infections were common throughout all the sample materials examined. Notice the two sizes of bacteria present, both coccus forms but distinctly different in size. Bacteria observed microscopically were consistently of the coccus form (1200X).

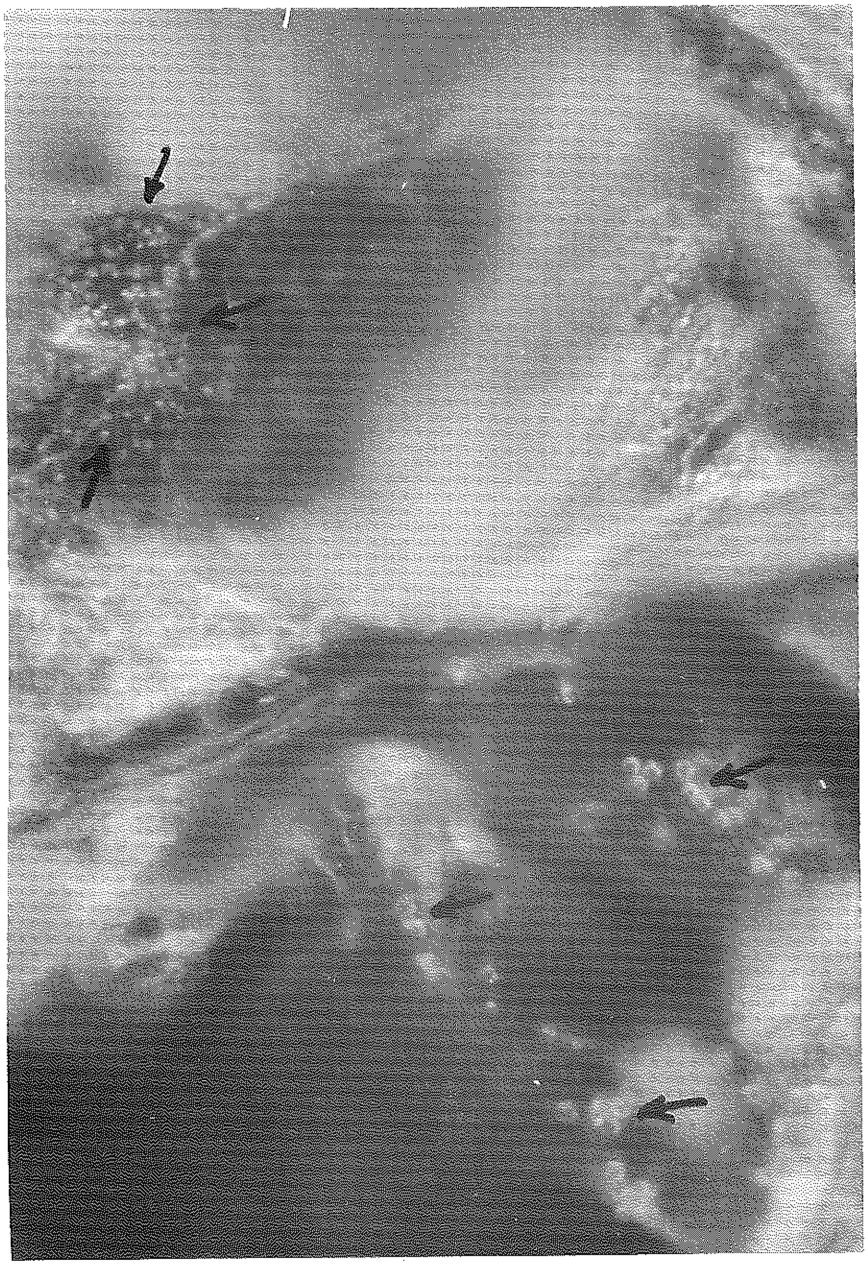


Figure 2.--Bacteria from one of numerous cultures obtained by isolation attempts from the grillage samples. Similar cultures were obtained from all samples. These bacteria were consistently found to be short rod forms occurring either singly or in short chains. No coccus froms of bacteria were obtained in culture. The absence of living coccus bacteria in the samples is throught to be due to the alcohol pickling of the wood samples.

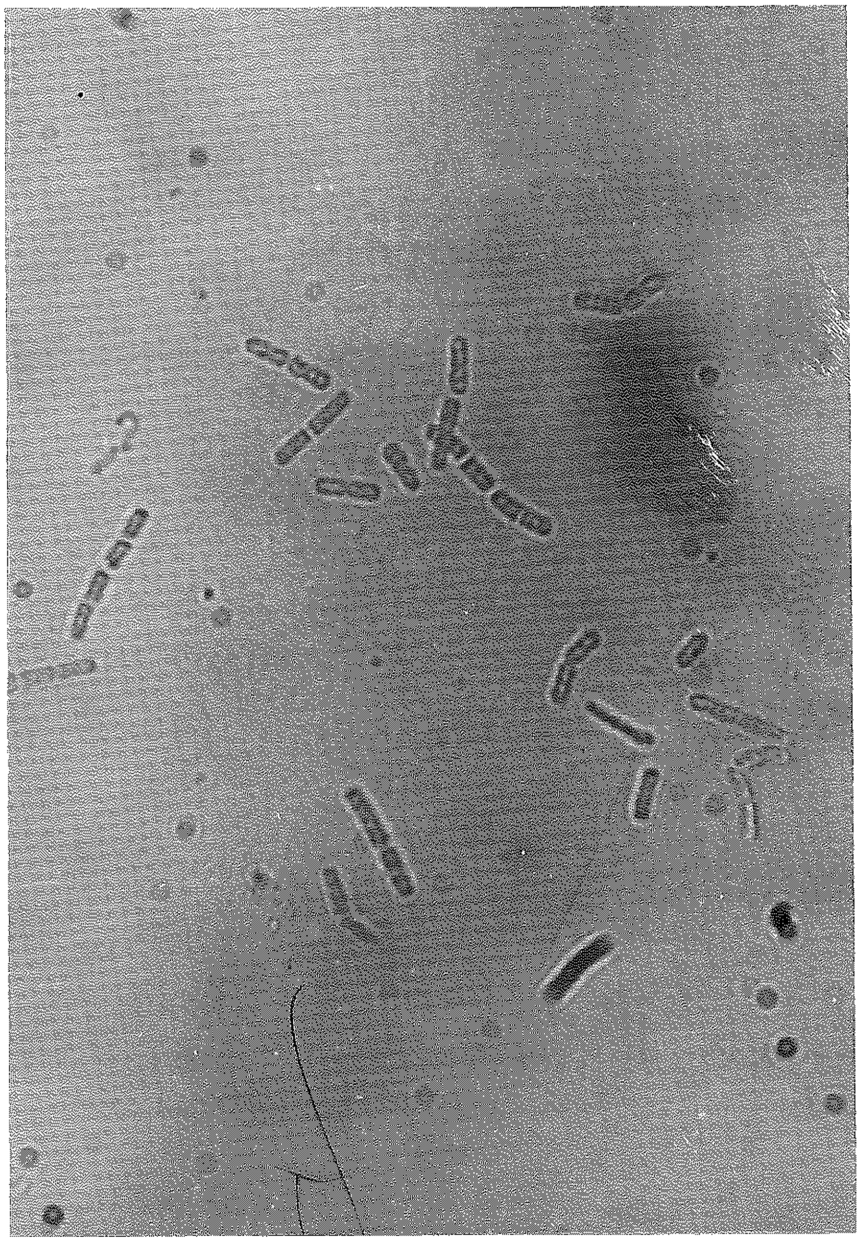


Figure 3.--Radial section of oak from a depth of 155.5 feet showing cell-wall compression failures. This physical defect could not specifically be attributed to any single for combination of causes with certainty, but such faults represent a significant decrease in strength. See text for possible explanation of cause (1200X).

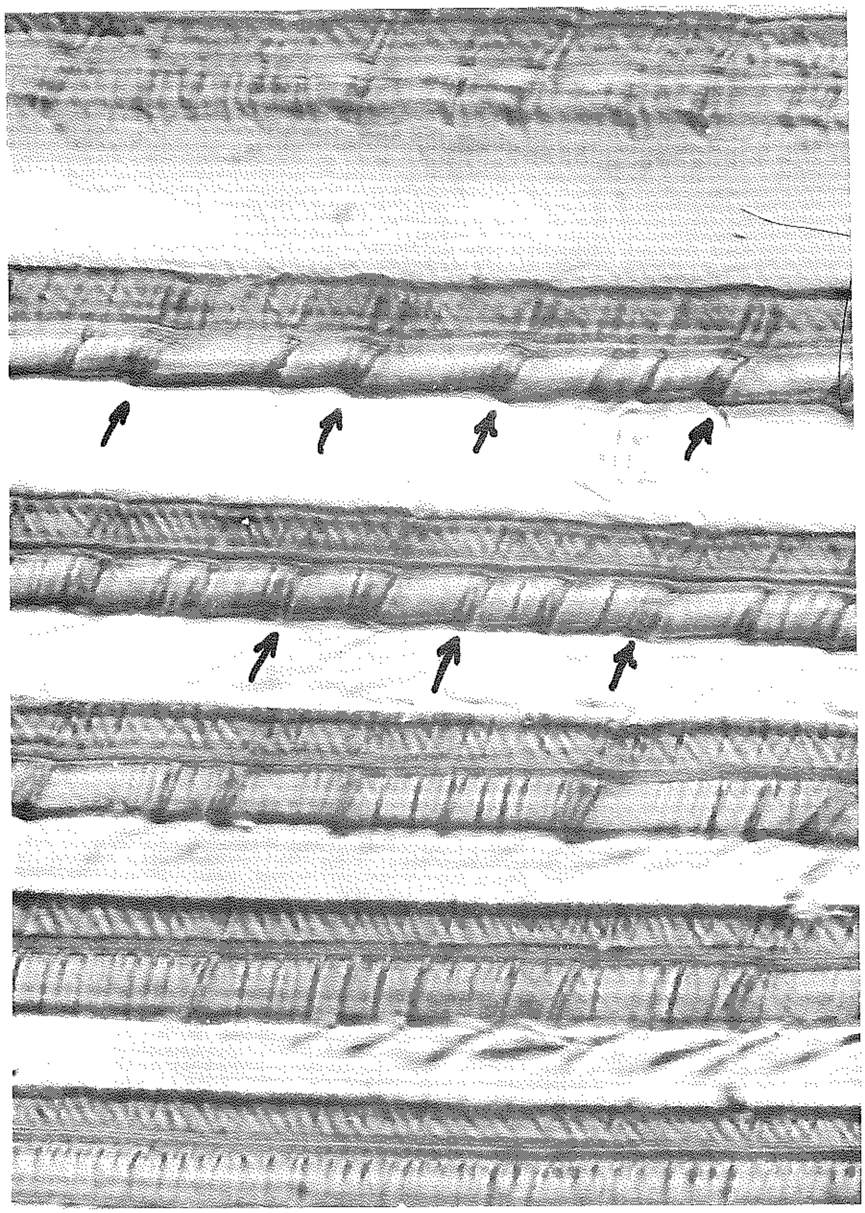
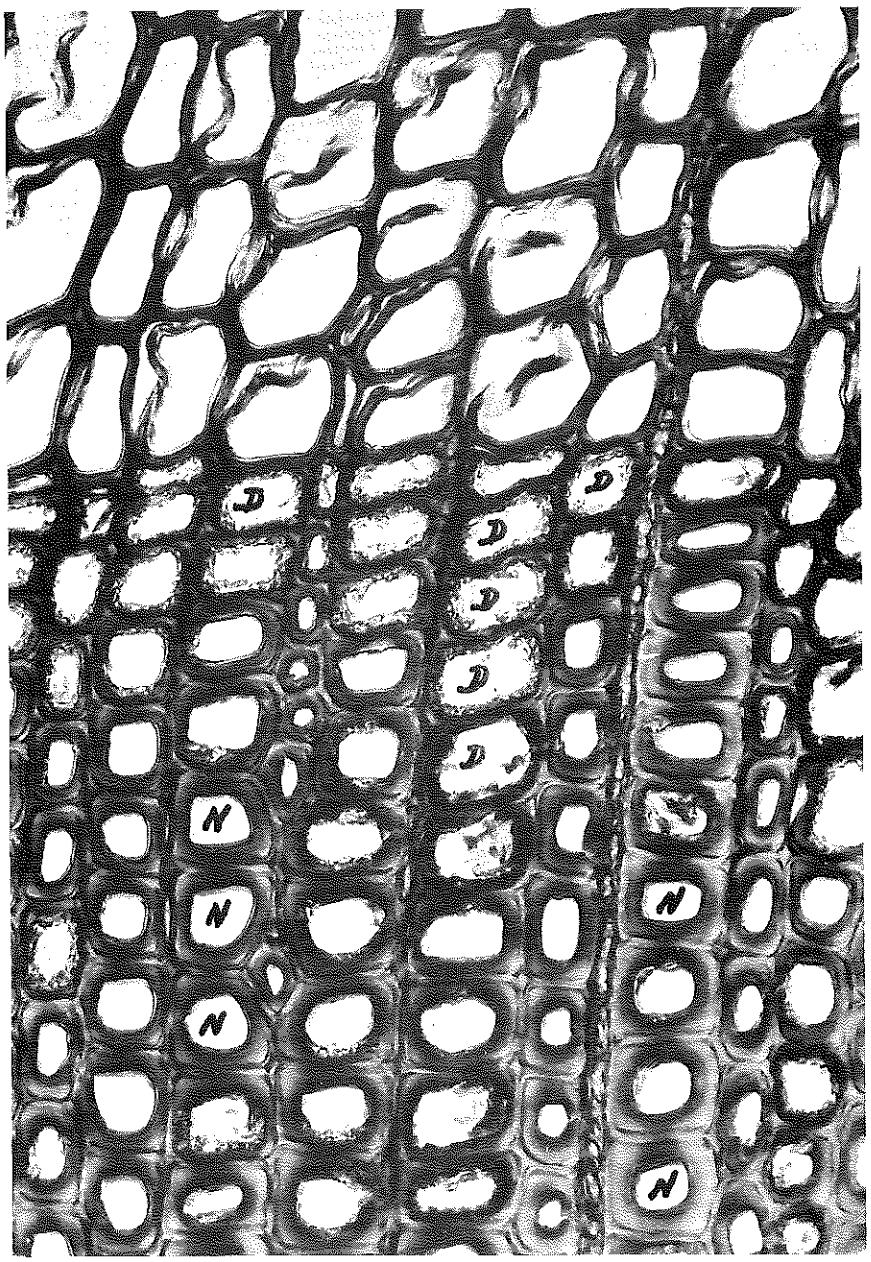


Figure 4.--Cross section of pine sample (156.5 ft.) showing cell-wall deterioration in the last three to 10 tracheids of an annual ring. This condition was observed repeatedly in this sample and may be due to biological (enzymatic) breakdown of the secondary cell wall. Whether such action has been the result of fungal or bacterial action was not determined, but from a practical point of view, it makes little or no difference--the end result is weakening of the wood. Normal cells are designated by N, deteriorated cells by D (380X).


D
D
D
D
D
D
N
N
N
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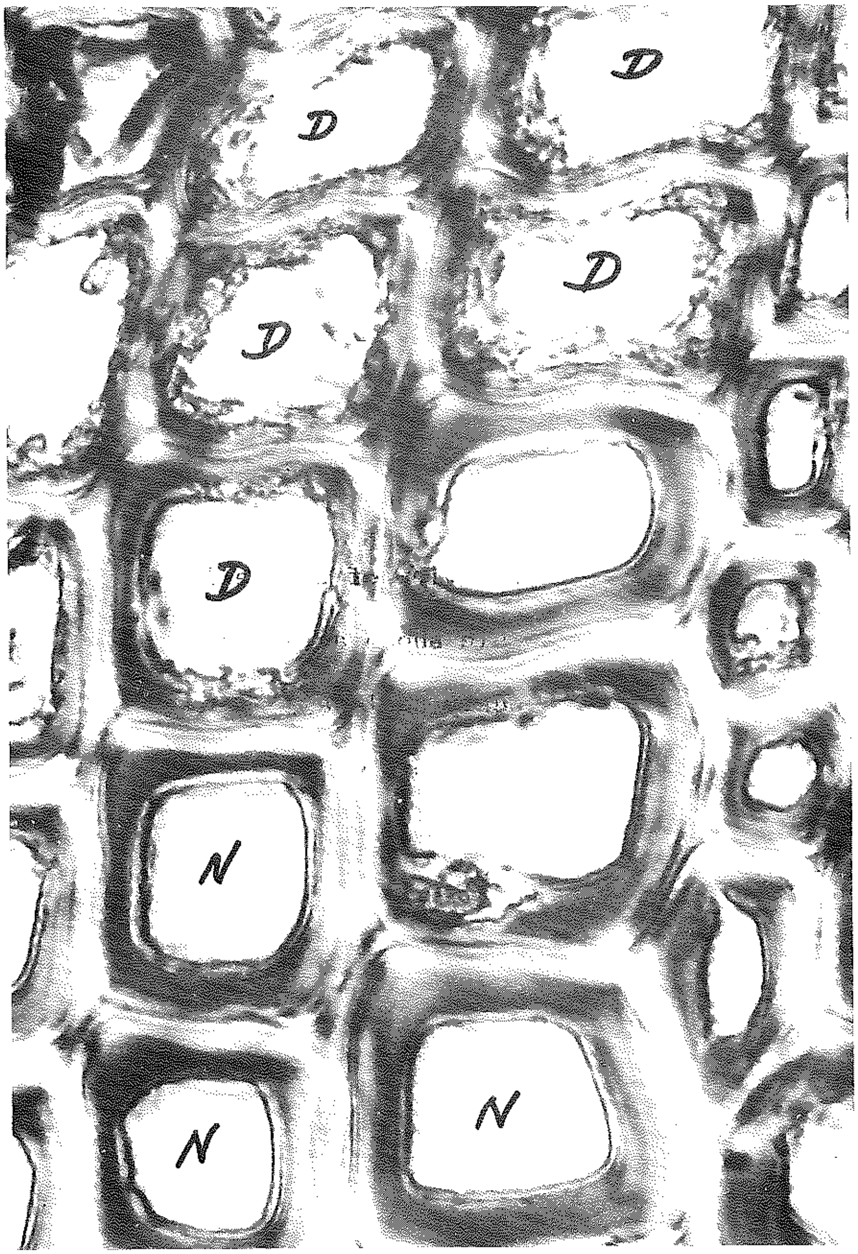
N

Figure 5.--A second view of the cell-wall deterioration in the pine sample shown at a greater magnification (1200X). Secondary cell-wall material deteriorated in cells marked _D_, cell walls normal in cells marked _N_.


D
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HAROLD TARKOW
and WILLIAM C. FEIST

The Superswollen State of Wood

The suggestion is made that the changes of certain physical and chemical properties of wood on mild pulping are caused by increased plasticization (fiber saturation point). A quantitative procedure is described for measuring the fiber saturation point of wood substance following such chemical treatments of wood. Conventional pulping procedures raise the fiber saturation point of all species of wood. With dilute alkali (1–2% sodium hydroxide) treatment, a marked difference is noted between hardwoods and softwoods. Softwoods are essentially unaffected by the treatment. The fiber saturation point of the hardwoods doubled. Chemically, this is accompanied only by deacetylation and an appreciable increase in free carboxyl content, which suggests cleavage of polyuronic ester bonds. The highly swollen condition can be recovered following air-drying. Wood in this superswollen condition should have the potential for novel uses.

Keywords: Fibers · Saturation · Swelling · Penetration · Cellulose · Hardwoods · Softwoods · Wood pulps · Chemical pulping · Deacetylation · Polyuronides · Chemical bonds · Carboxyl groups · Esters

THE colloid chemist uses the term "limited swelling gel" to describe a material that has a limited but reversible swelling capacity. The classical example of this is agar, in which swelling is limited by restraints imposed at the time of gelation. In this sense, wood substance is a limited swelling gel. The restraints in wood substance that limit swelling are "cross-links" composed of crystalline regions, of hydrogen-bonded regions too small or irregular to be detected by X-ray diffraction, and possibly of primary valence bonds between polymeric components. These restraints were introduced when the wood substance formed and "gelled" during secondary thickening of the cell wall. The properties of whole wood suggest similarity in swelling capacity of wood substance. Volumetrically, it is about 45%. The fiber saturation point of most species, because of the constant density of wood substance, is 30–40%.

In this paper, a brief review of the effect of certain chemical treatments on some properties of green wood is given, followed by a description of a procedure for quantitatively measuring the fiber saturation point, and a discussion of the probable mechanism responsible for the observed increase in fiber saturation point. This condition of the swollen substance with the increased fiber saturation point is referred to as the "superswollen state."

REVIEW OF LITERATURE

Effect of Certain Mild Treatments on the Strength of Green Wood

The wet strength of green wood is about 70% of the dry strength. The wet strength of paper is 1–5% of the dry strength. Klauditz (*1*) stated that an explanation in terms of simple delignification would be inadequate, because fiber separation and reconstitution are also involved. He treated green sticks (0.3 by 3 by 16 cm) with acidified sodium chlorite, washed out the chemical, and measured the strength of the wet structurally intact holocellulose. His data are summarized in Table I.

Delignification reduced the green tensile strength of wood by about 85%. Similar reductions were found for bending and compressive strengths. Klauditz interpreted the results in terms of a "hydrophobic action of the lignin," which means the removal of the lignin allowed for an increased moisture adsorption.

Klauditz also studied the effect of dilute alkali (*2*). Sticks of green wood were immersed in 0.2% sodium hydroxide, washed, and the wet tensile strength was measured.

After 10 hr, although the yields were about 94%, the wet strength had dropped at least 50%. About 60% of the 6% loss in yield was due to loss in acetyl content. Thus, with the loss of only 2–3% of basic substance, an appreciable loss in wet strength had occurred. Klauditz attributed this to an increase in hydration capacity resulting from a loss of acetyl groups. Apparently the "normal" lignin that is present does not necessarily preclude additional hydration.

Confirmation and extension comes from work by Lagergren *et al.* (*3*). The wet tensile strengths of a hardwood and a softwood treated with 2.5% sodium hydroxide for 2 hr (room temperature, unwashed) were measured. The hardwood lost 75% of its wet strength; the softwood lost only 17%. Thus, the hardwood is much more sensitive to alkali. It is recognized that satisfactory cold soda pulps cannot be made with softwoods.

Effect of Treatment on the Anisotropic Diffusion Characteristics of Water-Soluble Electrolytes

The diffusion rate (D) of a water-soluble material through water-logged wood is a highly anisotropic property. According to Stamm (*4*), $D_{\text{longitudinal}}/D_{\text{transverse}}$ (D_l/D_t) is about 15. Be-

Table I. Wet Tensile Strength of Structurally Intact Holocellulose

Species	Yield, %	Lignin, %	Pentosan, %	Acetyl %	Wet tensile strength,[a] kg/cm²	Reduction in wet tensile strength %
Beech	100	23.3	23.4	4.84	919	..
Beech holowood	77.8	3.1	28.4	6.32	116	87
Aspen	100	23.3	20.9	4.53	442	..
Aspen holowood	76.0	1.9	27.6	5.81	75	83

[a] Based on wood area. Conclusions were similar when based on area of cell wall.

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Table II. Diffusion Characteristics of Water-borne Solutes in Modified Wood

Wood	*Treatment*	*Yield, %*	D_l, *cm²/sec*	D_t, *cm²/sec*	*Relative* D_l	*Relative* D_t	*Increase in* D_t, *%*	*Reference*[a]
Softwood	None	100	0.8×10^{-5} (sodium chloride)[b]	0.02×10^{-5}	1	0.033	...	(5)
Softwood	Sulfite	91	(potassium chloride)	...	1	0.14	330	(6)
Softwood	Sulfite	85	(potassium chloride)	...	1	0.20	500	(6)
Softwood	Kraft	60	0.84×10^{-5} (sodium hydroxide)	0.36×10^{-5}	1	0.43	1300	(7)
Softwood	6% NaOH	...	(sodium chloride)	...	1	0.046	40	(8)
Hardwood	None	100	(sodium ion)	...	1	0.16	...	(9)
Hardwood	20 hr at pH 13.5, 25°C	...	(buffer chemical)	...	1	0.78	500	(9)

[a] Numbers refer to Literature Cited references.
[b] Diffusing chemical shown in parentheses.

cause of the high ratio of length of lumen to cell wall thickness (about 500), the resistance to *longitudinal* diffusion resides mainly within the lumen. The contribution to the overall resistance by the cell walls is very small. Consequently, one would expect modifications of the cell wall to have relatively little effect on the longitudinal diffusion characteristics of water-borne solutes.

The pathways for diffusion in the *transverse* direction, however, are more complex (*4*). Yet, because the ratio of lumen diameter to cell wall thickness is considerably smaller (about 10), a substantial contribution to the overall transverse resistance derives from the resistance within the cell walls. On modifying the cell walls one would expect a marked change in transverse diffusion characteristics. The data in Table II were collected from several sources.

All conventional pulping procedures of the softwood, with the exception of cold soda (6% sodium hydroxide), produced a marked increase in D_t (for example, 330% increase with 91% sulfite yield). Presumably then, the conventional pulping procedures disrupt the cell walls to a degree sufficient to make them more permeable to water-borne solutes of low molecular weight. With the hardwood, the very mild alkali treatment also had a very pronounced effect in disrupting the cell walls.

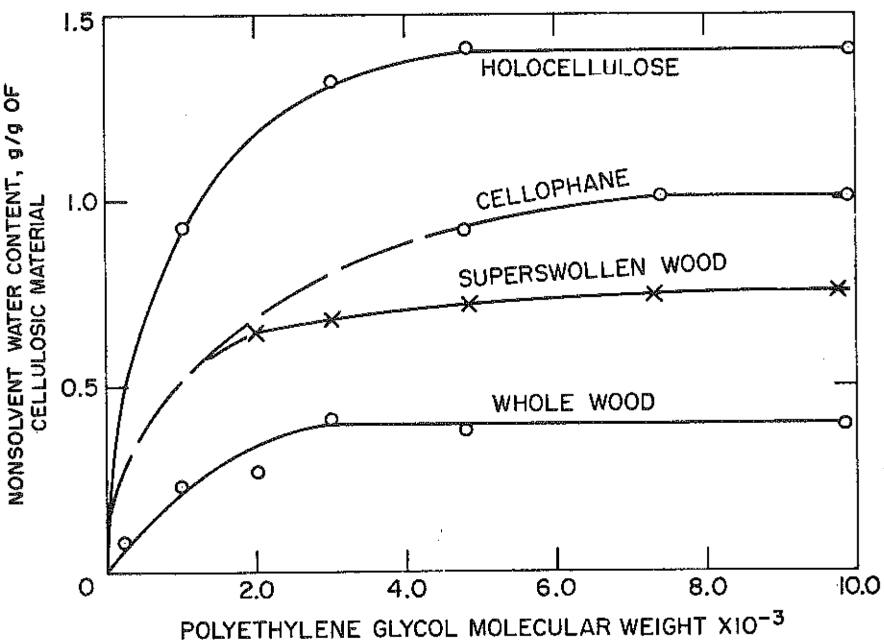

Fig. 1. Relation of molecular weight of polyethylene glycol to nonsolvent water content for water-logged whole wood; for water-logged holocellulose; for previously water-washed, air-dried, and rewetted cellophane; and for superswollen wood.

Effect of Treatment of Wood on Subsequent Attack by Cellulolytic Bacteria

Stranks (*10*) studied the action of the cellulolytic bacteria *Ruminococcus flavefaciens* from rumen fluid on treated and nontreated woods. Treatment consisted of heating wood meal with 1–5% sodium hydroxide at 150°C for 1 hr, followed by washing and drying. Digestibility was measured in terms of succinic acid production. Digestibility of alpha-cellulose was high and was assigned a value of +4 (Table III).

The action of the cellulolytic bacteria was negligible on the untreated and the alkali-treated softwoods. With the hardwoods, although the action on the untreated wood was variable, alkali treatment made them about as digestible as alpha-cellulose. The moderate digestibility of the untreated aspen and the untreated ash was undoubtedly due to the presence of tension wood. Abnormal wood, such as this, contains appreciable quantities of nonlignified polyglucan tissue (*11*). The alkali treatment significantly increased the digestibility of the lignocellulose tissue in hardwoods with the removal of only a small amount of lignin.

It is interesting that the reference material, alpha-cellulose, had a high digestibility. A high crystalline phase content, then, is not a deterrent to bacterial action on cellulosic material.

These examples show that certain mild treatments produce marked changes in some properties of wood. These changes are related to alterations in the physical structure of the wood substance. It is suggested that the change within the wood substance results in an increased swelling capacity. This change in swelling capacity can be evaluated quantitatively.

Table III. Digestability of Alkali-Treated Wood by a Cellulolytic Bacterium[a]

Species	*Untreated*	*Treated*
Douglas-fir	Trace	Trace
White pine	Trace	+1
Larch	Trace	+1
Aspen	+3	+3
White elm	Trace	+3
Basswood	Trace	+4
Ash	+2	+4
White birch	Trace	+4

[a] Heated 1 hr at 150°C in 1–5% sodium hydroxide.

MEASUREMENT OF THE SWELLING CAPACITY OF WOOD SUBSTANCE

The swelling capacity of wood substance, as a good approximation, is measured by the amount of moisture associated with the substance at 100% RH, or the fiber saturation point. This is readily determined for unmodified wood. In previous work (*12–14*) a procedure is described for measuring the fiber saturation point of modified woods and of certain pulps. It is based on measuring the amount of solute-free water in a waterlogged specimen equilibrated with a dilute solution of a water-soluble polymer whose molecular size precludes penetration into the wood substance.

Table IV. Fiber Saturation Point of Sitka Spruce Holocellulose with Varying Lignin Content

Lignin content, %	*Lignin removal, %*	*Fiber saturation point, %*
29.05	0	...
21.54	26	63
16.98	42	70
10.66	63	94
5.53	81	130
3.27	89	140
1.11	96	180

Table V. Effect of Alkali Treatment and Acid Wash on Fiber Saturation Point

Treatment	*Fiber saturation point, %*
Maple	
None	40
1% NaOH, 25°C, 3 hr	73
1% NaOH, 25°C, 6 hr	69
1% NaOH, 25°C, 18 hr	66
1% NaOH, 60°C, 3 hr	65
4% NaOH, 25°C, 6 hr	68
Douglas-fir	
None	32
1% NaOH, 25°C, 3 hr	36
4% NaOH, 25°C, 3 hr	32

Table VI. Effect of Liquid Ammonia Treatment on the Fiber Saturation Point of Maple

Treating condition	*Fiber saturation point, %*
−33°C, 1 hr	43
+30°C, 1 hr	51
+30°C, 18 hr	70

Table VII. Fiber Saturation Points of Sitka Spruce Sulfite Pulps

Yield, %	*Lignin content, %*	*Fiber saturation point, %*
100	29.5	35
85	23	64
75	17	76
67	12	99
52	3.8	104

EXPERIMENTAL

Wood

Transverse sections 20-mil-thick of green Sitka spruce and sugar maple were used.

Holocellulose

Cross sections 20-mil-thick of Sitka spruce were treated by the modified sodium chlorite method (*15*). The washed holocellulose retained the geometrical form of the wood very well.

Alkali-Treated Wood

Sections 20-mil-thick of green maple and Douglas-fir were treated with dilute sodium hydroxide (1–4%) and washed with water, dilute acetic acid and water.

Liquid-Ammonia Treated Wood

Sections 20-mil-thick of air-dried maple were immersed in liquid ammonia at −33 and at +30°C (under pressure), followed by air-drying and washing.

Sulfite-Pulped Wood

Sections 20-mil-thick of green Sitka spruce were heated with 16% sodium bisulfite at 160°C for different times, filtered, washed, and dried at 80% RH.

Determination of Critical Molecular Weight for Nonpenetration into Green Wood Substance

In Fig. 1 the nonsolvent water content (*13*) for several water-logged cellulosic materials is shown as a function of the molecular weight of polyethylene glycol (PEG). The critical molecular weight is 3000–6000; in other words, depending on the cellulosic material, the molecular size of the glycol above which penetration does not occur is 3000–6000. The nonsolvent water content measured at and above this molecular size is identical with the fiber saturation point and is a measure of the swelling capacity of the material. Figure 1 shows a four-fold range in swelling capacity.

At 90% RH and below, the equilibrium moisture contents (EMC) of holocellulose and wood are similar. The considerably higher EMC of the holocellulose at 100% RH (Fig. 1) suggests that pockets of liquid water are present (perhaps hundreds of angstroms in size), and are communicating with the environment through channels, or "bottlenecks," the sizes of which are equivalent to those of the critical molecular sizes of the polyethylene glycol. Fiber saturation points of the cellulosic material described in this report were measured with PEG-9000. Measurements were made in triplicate with a reproducibility of ±2%.

RESULTS

Effect of Conversion to Holocellulose with Different Lignin Contents

In converting to holocellulose, the removal of 90% of the lignin from Sitka spruce specimens resulted in a fiber saturation point of about 140% (Table IV). The volume of the additional water associated with the wood substance was several times greater than the calculated volume of lignin removed. Consequently, the wood substance must have undergone considerable swelling on conversion to holocellulose.

Examination under the microscope of green sections before and after delignification revealed an appreciable increase in cell wall thickness. Stone and Scallan made similar interpretations (*16*). Although drying and rewetting of the holocellulose resulted in some loss in fiber saturation point, the loss became negligible if the rewetting was made at 100°C.

Effect of Treatment with Dilute Alkali

The effect of alkali treatment on maple and Douglas-fir is shown in Table V. Three conclusions are drawn from this table:

1. Dilute alkali has little effect on the fiber saturation point of the softwood
2. Dilute alkali has a marked effect on the fiber saturation point of the hardwood
3. With the hardwood, there seems to be an increase in fiber saturation point that is roughly independent of alkali concentration and temperature. The maximum fiber saturation point is 73% for the alkali-treated, acid-washed wood. Evidence is now available that this same maximum fiber saturation point is reached with treating times considerably less than 3 hr. Preliminary chemical analysis shows that the only distinctive changes are a reduction in acetyl

content and a threefold increase in carboxyl content, as measured by calcium ion exchange. The formation of carboxyl groups following alkali treatment and even following sodium chlorite treatment has been demonstrated by Sarkar in his extensive work with jute (*19*). Sjöström (*20*) has also reported marked increases in carboxyl group content following alkali treatment. A valuable clue in Sjöström's findings is that the increase in carboxyl content following alkali treatment is considerably greater for hardwoods than for softwoods.

Effect of Treatment with Liquid Ammonia on the Fiber Saturation Point

The maximum fiber saturation point of maple treated with liquid ammonia (Table VI) is the same as that obtained by dilute alkali treatment (Table V). If the increased swelling capacity is due to the breaking of certain swelling restraints, the same restraints must be broken by both treatments. Although liquid ammonia causes a partial transformation of cellulose I to cellulose III, the alkali treatment described here is inadequate to produce any mercerization effects (*17*). An explanation for the similarity of caustic and liquid ammonia treatments could involve similar breaking of polyuronic ester bonds.

Alkali solutions very readily saponify these bonds and form free carboxyl groups. Ammonolysis would also cleave these bonds and form amides. The net result with both treatments is the elimination of primary valence cross-links between certain polymeric components. The occurrence of ammonolysis has been demonstrated by Wang (*18*). In fact, the kinetic implications suggested in Table VI agree with those reported by Wang.

Effect of Sulfite Pulping on Fiber Saturation Point

A considerable increase in fiber saturation point occurred with decreasing yield of sulfite pulp from Sitka spruce (Table VII). The effect was not as pronounced as that noted with holocellulose (Table IV). Recent unpublished work at the Forest Products Laboratory has shown that this may be due to the different temperatures at which the two pulping treatments were made.

DISCUSSION

The results of the literature survey now become understandable. Conventional pulping of hardwoods and softwoods and alkali treatment of hardwoods result in a marked increase in the swelling capacity of the wood substance. Stated differently, the substance becomes more highly plasticized. Limited chemical data suggest that this effect is accompanied by considerable increases in carboxyl content; this is very likely a result of the breaking of polyuronic ester bonds, that is, the breaking of cross-links.

A hallmark of recent polymer theory is the prediction and confirmation of appreciable reductions in swelling capacity of polymers following the introduction of relatively few cross-links. Stark and Rowland (*21*) have done related work with formaldehyde-cross-linked cellulose. Perhaps the increased swelling capacity discussed in this report is the reverse effect. We are suggesting that the phenomena described in the Review of Literature section of this paper can be understood as being due to an increased plasticization of the cell wall. The magnitude of this increased plasticization is given by the increase in swelling capacity. The substance within the cell wall at 100% RH can be considered to be in a superswollen condition.

Sjöström (*20*) reported a slight increase in carboxyl content in softwoods following treatment with alkali. Yet we have observed no increase in swelling capacity with softwoods. Perhaps saponification of polyuronic ester bonds is necessary, but not sufficient to obtain this effect. Other less alkali-sensitive bonds may exist in softwoods. Perhaps the effect is related to the considerably higher lignin content or to its different distribution in softwoods (*22*). Furthermore, the structures of the glucurono-xylans in hardwoods and softwoods are considerably different (*23*).

The swelling capacities reported here for alkali-treated wood are for the acid-washed material. Higher swelling capacities are found for washed, but not acid-washed material. The modified wood with its liberated carboxyl groups is behaving toward changes in pH much as any conventional ion exchange resin behaves.

Previous work at our laboratory has shown that the moisture adsorption isotherms of pulps and of wood are similar below 90% RH; yet as this investigation shows, the adsorption of pulps at 100% RH is considerably higher. It is suggested that the function of a wet-strengthening resin is simply a partial restoring of the swelling capacity characteristic of the original wood.

Because the critical molecular size of most modified cellulosic materials is equivalent to or less than that of PEG-6000, it must be concluded that cellulolytic enzymes do not diffuse freely through water-swollen tissues. Wood-rotting fungi circumvent this difficulty by sending out hyphae. This raises some significant questions. How do cellulolytic bacteria function? Why does increased plasticization of cell wall tissue increase the rate of attack by some of these bacteria? Does this increased plasticization explain the increase in digestibility of straw when treated with dilute alkali (*24*)? Is wood substance in the superswollen state accessible to digesting organisms within the lumen despite the presence of lignin? This last question is particularly significant for this day of food shortage and population explosion.

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Condition Of Pine Piling Submerged 62 Years In River Water

14th Street Bridge Over Potomac River, Washington, D.C.

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IN 1963, THE question was raised by the bridge engineers as to whether the piling under the old 14th Street Bridge in Washington, D.C., was sufficiently sound to warrant constructing a new bridge on it. Our examinations in 1963 and 1967 of wood from representative piles indicated that it probably was not, but it was decided in 1968 that this should be corroborated with a third set of samples, and strength evaluations of the wood. The conditions of the piling was of more than practical interest because it gave us an opportunity to observe the condition of untreated wood with an authenticated history under fresh water for a long period of time.

In response to our desire to analyze more of the piling, Mr. George Mc-Swain of the Washington office of the Forest Service, in collaboration with the engineer on the 14th Street Bridge, Mr. H. Emekli, arranged to have four more sections of piling sent to the Laboratory. These were examined microscopically and specimens from them were tested for strength. The findings, and conclusions derived from both the present and the earlier assays, are the subject of this report.

According to Mr. Emekli, the four sections had never been encased in concrete, since the concrete encasement on these particular piles started several feet below mudline. The sections were all from pier 9. Two of them, which will be referred to here as pile L1 and pile L2, came from just above the mudline; the other two, pile L3 and pile L4, came from just below the mudline, according to Mr. Emekli. The species of pine could not be established, but it seems logical to assume that it was one of the four major southern pines.

The sections were tested for strength in compression parallel to the grain. Specimens were 1 by 1 by 4 inches and they were tested in the green condition in accordance with the procedure outlined in ASTM D143. The location of the specimens is shown in Figure 1. The results are shown in Table 1.

The residual strength of the piles cannot be analyzed relative to known initial values, but it is possible to obtain some estimate of strength change

(Continued on page 24)

Table 1 — Results of compression parallel to grain test of 1 by 1 specimens cut from pile sections obtained from pier 9 of 14th Street Bridge, Washington, D.C.

Pile No.	Location in structure	Type of wood	Moisture content	Specific gravity	Crushing strength: Individual	Crushing strength: Average of specimens[1]
			Pct.		P.s.i.	P.s.i.
L1	Above mudline	Sapwood	113	0.430	1,380	—
			132	.394	1,200	1,290
		Sapwood	120	.395	1,140	—
			115	.402	1,420	1,280
		Heartwood	142	.420	1,320	—
			108	.434	1,680	1,500
L2	Above mudline	Sapwood	139	.421	1,550	—
			89	.465	1,310	1,430
		Heartwood	154	.381	1,370	—
			182	.380	1,250	1,310
		Heartwood	184	.369	1,040	—
			153	.399	1,280	1,160
L3	Below mudline	Sapwood	120	.390	2,230	—
			138	.367	2,180	2,200
		Heartwood	49	.431	2,880	—
			46	.429	2,840	2,860
L4	Below mudline	Sapwood	96	.424	2,740	—
			105	.435	2,920	2,830
		Heartwood	46	.446	3,370	—
			49	.453	3,200	3,280
		Heartwood	68	.430	2,880	—
			85	.414	2,650	2,760

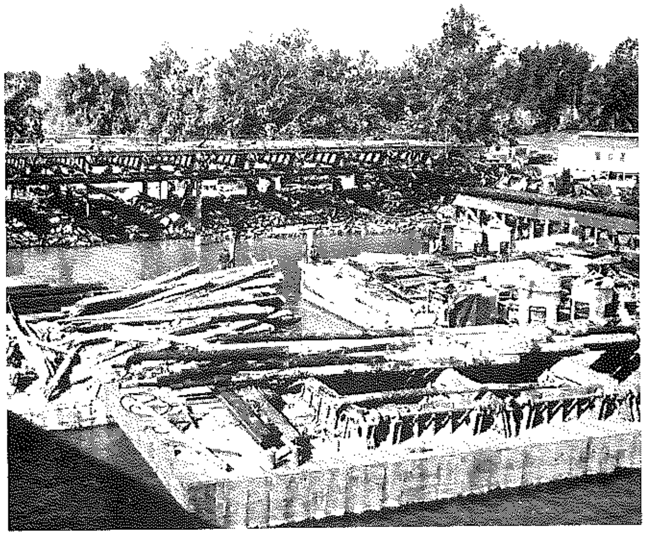
[1]Average values (Wood Handbook) for sound, green southern pine wood:
Loblolly — 3,490 Longleaf — 4,300
Shortleaf — 3,430 Slash — 4,340

[1]Deceased.
[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

It has generally been assumed that timber piling need not be pressure-treated for use in fresh water installations, however, this recent report on pilings removed from the old 14th Street Bridge across the Potomac River in Washington, D.C., prompts a reevaluation of this established thought.

When the old bridge was dismantled, after nearly 60 years of service, piling and piers were found to be insufficiently sound for the construction of a new bridge. Pilings were sent to the Forest Products Laboratory at Madison, Wisconsin for detailed study. This examination revealed that even though these piles had been in fresh water, the timbers above the mudline had less than one-half their original strength, and below mudline they had no more than about 80% of their original strength.

This FPL report is presented to show the results of the examination by the Forest Products Laboratory. The many aspects of this report are worthy of further analysis and consideration by specifiers and users of timber products. It seems prudent to avoid possible material deterioration in fresh water installations by specifying the use of pressure-treated timber piles. — **WOOD PRESERVING**



The pilings that are on the barge are a few that were pulled when the 14th Street Bridge was razed.

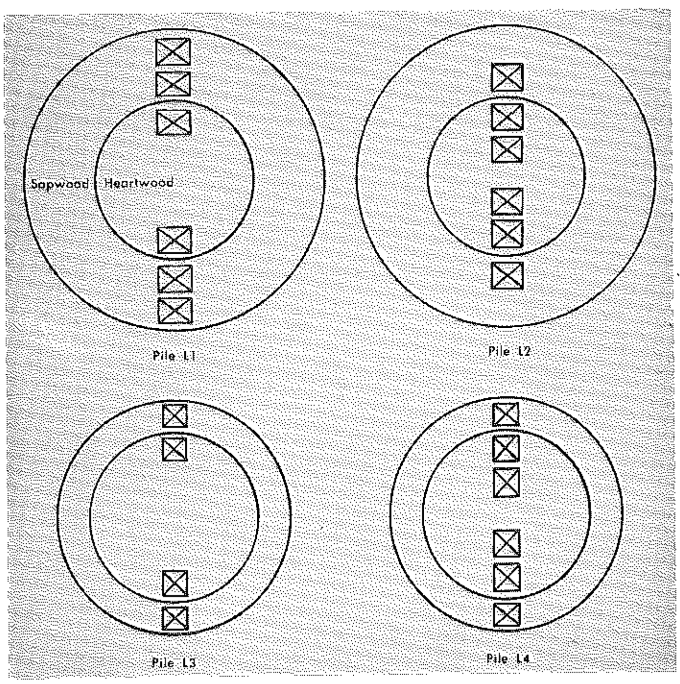


Diagram for cutting 1" by 1" compression parallel to grain specimens from pile sections obtained from pier 9 of the 14th Street Bridge, Washington, D.C.

by referring to the *average* crushing-strength (parallel to grain) values for southern pines. Using for reference the average strength of the weakest of the southern pines, loblolly and shortleaf (Table 1), one could conclude that the wood above mudline tended to have less than one-half its original strength and that below mudline no more than about 80 percent of its original strength. Thus, it seems that there was a definite and substantial reduction in crushing strength of the piles above mudline and a moderate reduction in strength below mudline. Although the apparent reduction in strength below mudline may not be statistically significant, it probably is a real one in view of microscopical evidence of bacterially caused changes in the wood.

The microscopical observations are summarized in Table 2. Bacteria were present in all portions of all pile sections. They were more prevalent in sections below mudline than in sections above, and the wood below mudline was correspondingly altered to a greater degree microscopically. The greater residual strength in the wood below mudline cannot be accounted for on the basis of the microscopical appearance of the wood, which was not as good as that of the wood above mudline. It can only be suggested at this time that microscopically visible alterations of pine wood induced by bacteria are not a reliable index of the changes in wood strength of the magnitude found in this piling.

Fungus hyphae were present in the sapwood and outer heartwood, but not in the inner heartwood.

We conclude from the total evidence that the pine sapwood below mudline in the river water for 62 years had been substantially weakened in crushing strength by bacteria. The heartwood was affected less; judging from the condition of wood recovered from lakes and river bottoms after much longer periods than 62 years, however, the heartwood also probably would eventually have been seriously degraded.

The fungus infection probably was incurred before the piles were driven, since fungi are not known to be capable of seriously invading wood under water, and limited fungus infection of southern pine poles and piling on the storage yard is common. The fungus infection however, did not appear to be extensive enough to have been a sizable factor in the apparent reduced strength of the wood. ■

Table 2 — Summary of microscopical observations of thin sections from pine piling obtained from pier 9 of 14th Street Bridge, Washington, D.C.

Pile No.	Location in structure	Type of wood	Miscroscopical examination: Bacteria	Fungi	Wood deterioration
L1	Above mudline	Sapwood (outer)	Few	Occasional hyphae	Nothing to indicate wood deterioration. There are a few ray parenchyma cells gone but appear to be torn out by cutting rather than due to attack.
L1	Above mudline	Sapwood (inner)	Few	Occasional hyphae	Nothing to indicate wood deterioration. There are a few ray parenchyma cells gone but appear to be torn out by cutting rather than due to attack.
L1	Above mudline	Heartwood	Few	Occasional hyphae	Ray cells intact, as well as fibers, but there are as many bacteria in heartwood as in sapwood.
L2	Above mudline	Sapwood	Few	Occasional hyphae	Bacteria mostly in rays or in fiber ends adjoining rays. Very few parenchyma cells attacked.
L2	Above mudline	Heartwood (outer)	Many	Many	Some of ray cells attacked. Bacteria and a few fungal hypha in rays. Many hyphae also in fibers; these have caused bore holes and a thinning of wall. Clamps on hyphae also indicate this is a basidiomycete fungus and probably a white rotter.
L2	Above mudline	Heartwood (inner)	Few	None found	Rays and pits essentially intact and no fungal deterioration found.
L3	Below mudline	Sapwood	Many	Few	Definite bacterial attack — mostly in vicinity of rays or in fiber ending of rays. Many pits are being attacked or are gone. Around pits and in general area there are *minute* elognated cavities — many of which follow the microfibrils. These cavities contain bacteria.
L3	Below mudline	Heartwood (outer)	Few	Few	Bacteria in rays have caused some deterioration but not extensively like in sapwood.
L4		Sapwood	Many	Moderate No. of hyphae	Same as L3 sapwood.
L4	Below mudline	Heartwood (outer)	Few	Few	Fibers and rays free from deterioration.
L4	Below mudline	Heartwood (inner)	Few	None found	Fibers and rays free from deterioration.

APPENDIX III

WILLIAM H. BURR'S REPORT TO ASCE (1890)

(Plates XV, XVI, and XVII have been omitted)

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

446.

(Vol. XXIII.—August, 1890.)

THE RIVER SPANS OF THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY

By WILLIAM H. BURR, M. Am. Soc. C. E.

WITH DISCUSSION.

The structure which forms the subject of this paper crosses the Ohio River at Cincinnati, Ohio, and with its approaches forms a part of the Chesapeake and Ohio Railroad system. It acquires its interest as a piece of engineering chiefly from the magnitude of the individual spans of which it is composed. There were no special engineering difficulties to be overcome either in the substructure or superstructure, but the central span of the three, 550 feet long between centers of piers, and 84 feet deep between centers of chords, is the greatest simple non-continuous truss span yet constructed. The two spans which flank the center or main channel span are 490 feet each between pier centers, with center depths of 75 feet; and the fact that all the spans carry a double track railway with two roadways and two sidewalks, renders them also the heaviest non-continuous trusses which have yet been built either in this country or in Europe. The detail drawings accompanying this paper show all the main features of the trusses and floor systems and their connections which are of any special interest. As they indicate, all the main parts of the trusses are of steel, while the lateral and transverse systems of bracing and the floor-beams and stringers are of wrought-iron.

With the exception of the connection between the floor-beams and posts, and the web system, there will be found few features not ordinarily included in the best American practice for heavy spans. All connections are central, and so designed as to eliminate essentially all secondary stresses. The system of web members used, and which has been developed by the Phœnix Bridge Company for its long spans, is seen to be single, and it is of interest in passing to note that if a single system of bracing may be used for trusses of the dimensions and weight of these under consideration, there would seem to be no case where it may not be advantageously employed. There is thus avoided all the ambiguity and secondary stresses which are inevitable to a greater or less degree when any multiple system of web members is used.

The boring of individual truss members was done with such lengths as would eliminate all secondary stresses whatever at a condition of loading intermediate between no moving load and a full moving load. As the latter condition of loading will very rarely occur, these normal lengths will reduce the secondary stresses to an absolute minimum; in fact, will reduce them to such small magnitude as to leave them with no importance whatever. The connection between the floor-beams and posts, which is made by means of close-fitting turned bolts in holes drilled with those members assembled, is of such a character as to secure all the advantages of a rigid connection and at the same time eliminate all tension upon the connecting bolts, leaving them to transfer shear only; at the same time the weights of both railway and highway floor systems are transferred centrally, so as to bring an equal distribution of weights upon all of the web members intersecting at any lower chord panel point. Under the requirements of the specifications all rivet holes in the plates and angles forming the upper chords and end posts, and nearly all intermediate posts, were made with multiple drills of six drills in a gang. The only exceptions to this statement were some light plates and angles in a few of the intermediate posts, which were punched and reamed.

Much difficulty was experienced in obtaining metal for the heavy plate links at the upper ends of the end posts which would fill the requirements of the specifications, or sufficiently near thereto. A number of steel plate makers felt confident of being able to produce such thick and heavy plates as would meet the requirements of this case, but repeated trials were failures. The metal would be very low in elastic limit as well as in ultimate, and develop porous places in the interior of the mass. The whole difficulty lay in the small amount of work which was put upon the metal between the ingot and finished plate. Messrs. Graff, Bennett & Co. finally produced a number of plates of open hearth steel which met the requirements of the specifications. Their financial difficulties coming on at this time, however, prevented their completion of more than a few only of the plates required. The remaining plates for these heavy links were made of Bessemer steel and produced at the Homestead Mills of Messrs. Carnegie, Phipps & Co. The experience with these plates was very interesting in itself, although the difficulties encountered threatened at one time to result in a serious delay to the progress of the work. It demonstrated in a peculiarly clear and effective manner the improvement in the quality of the metal produced by an increased amount of work. The most porous portions of several plates were a number of times worked down under a hammer to bars of most excellent steel, alike in respect to its elastic limit, ultimate resistance and ductility.

The 7-inch steel eye-bars were forged from open hearth steel, while the 8-inch bars were forged from Bessemer steel.

The steel pins were forged from open hearth metal.

Before proceeding with the actual shop work on these spans, many careful tests on the effect of the various shop manipulations of the steel material were made in order that the greatest confidence might be placed in the resulting work. Rivets both with counter-sunk and full heads on one and both sides of plates were driven, and the hammering continued throughout the stage of blue heat as the metal cooled down; heads were then knocked off, or the counter-sunk rivets driven out in such a way as to give their material as much abuse as possible. The results of these tests were in every way highly satisfactory and showed that the material selected was admirably adapted to its purpose. They also revealed the fact that with proper material in steel rivets, that is, with phosphorus not over about five hundredths of firmly for a number of hours with the flood at about its maximum height, and the water commenced to recede within six hours after the failure. Contrary to usual experience the river maintained its high water during the entire month of September and the early part of October, although it receded for short periods, at several intervals, from 5 to 17 feet.

The Phœnix Bridge Company at once ordered new lumber for false work, traveler and piles at as many points as possible in Ohio, Indiana and Georgia, so as to insure the concentration of the largest quantity in the shortest time. New hoisting apparatus also had to be ordered and an extensive electric light plant was founded and started within four days after the wreck, and the entire bridge site was thus illuminated and all the operations of pile-driving, placing false work and erection of the iron and steel work was actively continued both day and night; in fact, from the day of the wreck, on August 26th, to the completion of the structure on December 25th, there was no cessation of operations either night or day. It became evident from the phenomenal character of the season that the usual autumn low water in the Ohio River was not to be experienced, hence in order to give the new false work of the 550 feet span thorough protection, two lines of heavy piling were run obliquely up-stream about 600 feet from each of its extremities, thus forming by their intersection a V-shaped protection, with the angle of the V about 550 feet up-stream. Each of these lines was formed by piles 5 feet apart centers, backed by a group of six piles every 40 feet. The two lines were then sheathed by 4 x 6 scantling. A depth of water 45 feet in the river would have just submerged this protection, but it was considered safe to neglect the expectation of such a rise, and subsequent events justified the anticipation. This protection was found to act most admirably and formed a complete safeguard to the false work against a number of rises in the river with very considerable amounts of drift.

So actively was the work prosecuted that just five weeks from the day of the wreck the entire false work, including piles, the two travelers and about 1 200 lineal feet of pile protection, were completed in place, the iron and steel floor once again being placed on the false work. During this time over 950 piles had been driven and nearly a million feet of lumber framed and placed in the false work and the two travelers; the traveler for the handling of the iron and steel being as

large as any ever constructed. The 700 000 pounds of iron and steel railway floor had within the same time also been entirely reconstructed from new material at the Phœnixville shops and delivered at Cincinnati. The erection of the iron and steel work of the 550-feet span was then pushed forward night and day, and was entirely completed, including the floor and all lateral and transverse bracing, on the 28th of October, and it was swung clear from the false work immediately thereafter. The coupling of this span was completed just after a heavy storm with a flood rise of 27 feet, making the third period of high water since the beginning of the work. This flood rise continued at or near its high water mark for some three weeks, and prevented the driving of any piles for that length of time in the north 490-feet span. During the last of November, however, the water commenced to recede and the remaining pile driving and false work were soon completed. On December 9th the first iron work for the railway floor was run out on the false work of the north 490-feet span at the Cincinnati end of the structure, and the erection of the remaining iron and steel work was carried on continuously day and night until the last coupling was effected, as stated, on December 25th. The placing and erection of all the iron and steel work of this span, including railway floors and all lateral and transverse bracing, was completed in sixteen days, on the last of which the first regular railway traffic passed over the bridge, from which time schedule trains were regularly run.

Substructure.*

The shore piers of the two 490-feet spans rest on piles capped transversly of pier with 12 x 12-inch white oak timbers, which in turn carry longitudinally of pier nine lines of the same 12 x 12-inch timbers. These latter carry a solid 12-inch white oak floor or platform about 72 x 36 feet, on which the masonry is placed. The piles are placed 4 feet apart, centers in both directions. They are white oak sticks driven to refusal 30 to 42 feet into the clay and gravel of the banks. There are five bottom courses of masonry, each 27 inches thick and each stepped off 12 inches. The masonry of the main body of the pier surmounts these bottom courses with the batter and dimensions shown on Plate XII.

* The writer is chiefly indebted to Mr. Epes Randolph, Chief Engineer of the Covington and Cincinnati Elevated Railway, Transfer and Bridge Company, for the ample notes on which the following account of the substructure work (frequently in the words of Mr. Randolph) is based, although Mr. Charles Sooysmith, M. Am. Soc. C. E., has also given him valuable assistance in several particulars.

an air compressor barge was lashed to it, connections made and air used to aid the false bottom to float the caisson. When launched June 2d, the caisson working chamber had only one course of the deck laid above it. From June 2d until June 20th the time was spent in completing the roof or deck of the caisson, after which it was floated into position behind a row of protection or guide piles V-shaped, with the angle up-stream. The Ohio caisson was settled to river bottom June 20th and rested on a level surface 7 feet below low water, and the false bottom was entirely removed July 1st by sawing into small pieces and shoving the portions under the cutting edge.

The pneumatic machinery and electric light plant were located on two barges alongside of the caisson and crib. The larger barge, 26 x 96 feet, carried two Ingersol duplex air compressors, two duplex Worthington pumps, 10 x 18, and three boilers. The other barge carried one $10\frac{1}{4}$ x 18 duplex Worthington pump, one 16 x 24, and one 18 x 30 Ingersol straight line compressor, one Knowles pump and three boilers and one dynamo with four arc lights of 1 200 candle-power each. Both barges contained machine shop requisites for such work as was found necessary to be done for the repair and maintenance of the entire plant. The air lock was located in the 4-foot cylinder of $\frac{3}{8}$-inch boiler iron running from the top of the working chamber through the deck and crib work about 18 or 20 feet above the top of the latter. As the caisson was sunk the cylinder was carried up section by section and masonry built around it. The inside of the cylinder carried a ladder 15 inches wide with $\frac{3}{4}$-inch round rungs 16 inches apart. The upper and lower doors or valves of the air lock both swung downward. When a section was added to the cylinder, which carried the air lock, the upper door was generally made a lower. In this manner the air lock was gradually carried up as the height of masonry increased. Each door or valve was 20 x 27 inches, built of $\frac{1}{2}$-inch wrought plate, to which was riveted a $1\frac{1}{2}$ x $\frac{1}{2}$-inch gasket ring and a $1\frac{1}{2}$-inch rubber gasket, making when closed a tight fit. These doors were raised and lowered by block and tackle. As the caisson descended and air pressure increased the time required for the equalization of pressure in the air lock varied from one-half to three minutes according to the pressure and to the ability of the parties descending to sustain the corresponding changes of pressure. A concrete shaft 1 foot 6 inches diameter of $\frac{1}{4}$-inch boiler iron with a door at top and bottom was located near the middle of the caisson. The equalizing in this shaft was done from above by means of a 4-inch pipe connection with the working chamber to give compressed air when the concrete was passed downward. It was only used after the caisson was in place for the purpose of supplying concrete to fill the working chamber. Both the air and concrete shafts and also the 4-inch pipes were bolted to the deck course forming the roof of the working chamber. Four-inch pipes were used to discharge gravel and sand from the working chamber. Small piles of gravel and sand would be gathered at the lower openings of the pipes, which projected 6 or 7 feet into the chamber, after which a valve in the pipe would be opened and the material forced up into the pipe and into the river by the compressed air. This method was pursued nearly the whole time and removed most of the material. The larger boulders, rocks, etc., however, were hoisted through the excavating shaft located near the concrete shaft. It was carried up through the deck and crib work about 3 feet square with its lower end terminating in cylinders about 4 feet long and 2 feet 8 inches in diameter, with two doors 1 foot and 1 foot 6 inches on opposite sides. This cylinder was bolted to the top of the working chamber and was entirely within it. The bottom was concave with a small hole 3 x 4 inches just above it. The material was raised in a bucket fitting closely inside this cylinder by means of a derrick on the boat alongside the caisson. There were two openings corresponding to the doors of the cylinder on the upper part of the bucket into which the boulders, etc., were thrown, after the air in the bucket had been equalized and the doors in the cylinder opened. The bucket was guided through the shaft by two beams projecting over its top, fitting into grooves in the sides of the shaft. For a short time at the beginning of the work this excavating shaft was not used, and boulders were carried down with the caisson, except a small quantity which was locked up through the air shaft in sacks. A sand pump attached to the Worthington pump above and to the ejector below, terminating in a 4-inch rubber hose and strainer, was in frequent use to remove sand, etc., the materials having been stirred up with a jet attached to the ejector just above it. Men worked in eight-hour shifts day and night until work was finished. Valves were attached to the lower end of the 4-inch pipes leading from the compressors to the air chamber with automatic closure, in order to give the men ample time to get out if accidents should happen to the air compressor.

Distance bed-rock to bed of river, 42 feet; average, 0.451 feet per day.

CONTENTS.

514 033 feet B. M. timber.
3 569.73 cubic yards concrete.
153 383.73 cubic feet displacement.
5 155.735 cubic yards volume.
4 550 barrels Louisville cement.
450 barrels Alsen's German Portland.

The Kentucky caisson remained in its first position about 12 inches up-stream.

No delay, except two weeks cutting logs and a short delay owing to insufficient weight on top, was experienced. The work went on smoothly all the time and was a perfect success.

The heat in both caissons was at times very great, and a few men were disabled by the so-called "bends," but no lives were lost, nor were the men apparently injured from working eight hours each shift continuously.

The following is a succinct statement of the masonry built upon the cribs over the two caissons at the ends of the 550 feet span:

Began Ohio pier September 24th, 1887.
Completed Ohio pier June 30th, 1888.
Began Kentucky pier September 17th, 1887.
Completed Kentucky pier June 9th, 1888.
Actual working days, about 130 Ohio, and 140 Kentucky pier.
Rate per day, approximately, $7\frac{1}{2}$ to 8 inches per day in height.

CONTENTS.

Limestone	3 431.603	cu. yds.	Kentucky pier.
Freestone	1 465.910	"	"
Oolitic stone	66.150	"	"
Total	4 963.663	cubic yards.	
Limestone	3 405.342	cu. yds.	Ohio pier.
Freestone	1 398.680	"	"
Oolitic stone	66.150	"	"
Total	4 861.172	cubic yards.	

The total weights, including lumber in substructure, concrete, masonry, iron and steel of spans, timber floor of same and maximum moving loads, on the various abutment and river piers of this structure, and the loads carried per pile on the abutment piers, and per square foot at bottom of caissons for the two river piers are as follows:

Ohio abutment pier, total weight	13 202 324	pounds.
Load per pile	77 200	"
Kentucky abutment pier, total weight	13 890 224	"
Load per pile	81 200	"
Ohio River pier, total weight	36 719 285	"
Total load per square foot	13 000	"
Kentucky River pier, total weight	36 922 285	"
Total load per square foot	13 047	"

The above total weights, sustained by the two river piers, are the actual total loads, less the buoyant effect of the displacement, the volume of which is given in the preceding data.

The pneumatic portion of the substructure, including all caisson and crib work, was performed by Messrs. Sooysmith & Co., during 1887 and 1888, in their usual efficient and successful manner.

OHIO RIVER BRIDGE BETWEEN COVINGTON AND CINCINNATI.—SPECIFICATIONS FOR THE MAIN SPANS.—BY THE PHŒNIX BRIDGE COMPANY.

The bridge proper shall consist of a central span of five hundred and forty-five (545) feet, center to center of end pins; and two side spans, each four hundred and eighty-six (486) feet, center to center of end pins.

The structure shall be built for a double track railway, with a wagon-way and a sidewalk on each side.

The clear distance between trusses shall be twenty-seven (27) feet, and the clear headway, measuring from base of rail to lowest part of the overhead bracing, not less than twenty (20) feet.

The distance from center to center of railway tracks shall be thirteen (13) feet.

The width in clear for each wagon-way shall be eleven (11) feet, and that for each sidewalk five (5) feet.

Strong outside railings, each weighing not less than sixty (60) pounds per lineal foot shall be provided for the sidewalks.

Wooden screens ten (10) feet high shall be provided between the wagon-ways and the railway tracks.

All parts of the structure, excepting cross-ties, guard timbers and flooring, shall be of iron or steel, the kind of metal for each member or class of members to be used being noted on the diagram of stresses.

This diagram shall also show the maximum stresses and sectional areas of all main members of the structure.

Provision shall be made for the free expansion and contraction of all parts, corresponding to a variation in temperature of one hundred and fifty (150) degrees Fahr.

As far as practicable all parts of the structure shall be accessible for inspection and painting.

On bearing surfaces, fifteen thousand (15 000) pounds for rivets and eighteen thousand (18 000) pounds for pins.

On main diagonals nearest the middle of the span, thirteen thousand (13 000) pounds tension.

For intermediate main diagonals the tensile intensities are to be directly interpolated.

In compression on top chords and inclined end posts, provided that the ratio of length to least radius of gyration does not exceed fifty (50), fourteen thousand (14 000) pounds.

For all other steel struts the intensities are to be found by the following formula:

$$R = \frac{14\ 000}{1 + \frac{1}{20\ 000}\ \frac{l^2}{r^2}}$$

where R is the intensity, l the length of column in inches, and r the least radius of gyration in inches.

Alternating stresses. Steel struts subject to alternating stresses of compression and tension shall be proportioned by the following formula:

$$R = \frac{14\ 000\left(1 - \frac{1}{2}\ \frac{\text{min. stress}}{\text{max. stress}}\right)}{1 + \frac{1}{20\ 000}\ \frac{l^2}{r^2}}$$

where R, l and r have the same signification as in the last clause.

Wind stresses. An addition of fifty (50) per cent. to all specified intensities of working stresses shall be allowed for all wind stresses and for all combinations of wind stresses with other stresses.

Compression members. The thickness of metal in compression shall not be less than one-sixteenth ($\frac{1}{16}$) of the distance between supports in line of stress, or less than one-thirtieth ($\frac{1}{30}$) of the distance between supports at right angles to the line of stress, or less than one-eighth ($\frac{1}{8}$) of the distance from the edge of plate of flange to line of support, or less than one-quarter ($\frac{1}{4}$) inch when both faces are accessible for painting, or less than five-sixteenths ($\frac{5}{16}$) of an inch when only one face is accessible for painting.

The ratio of length of strut between supporting points to its least diameter shall not exceed forty-five (45).

Eye-bars and upset rods. The eyes and threaded parts of bars and rods shall be so proportioned as to develop the full strength of the members. The heads shall not be welded to the body of the bar.

Long tension members shall be supported at suitable intervals to avoid rattling and undue stress by bending. No lateral or sway-rod shall be less than one (1) inch in diameter.

Pins and rivets. Pins shall be proportioned to resist the bending as well as the shearing forces acting upon them.

The limits of stress specified for shearing and for the pressure on bearing surface of holes shall determine the number and size of the rivets.

Plate girders. In designing plate girders the office of the web shall be to resist shear only, and that of the flanges to resist bending only.

The thickness of the web shall never be less than a quarter ($\frac{1}{4}$) of an inch, and it shall be in all cases properly stiffened.

Connections and attachments. Connections and attachments of all members shall be so designed that the stress on each member can be correctly calculated. Whenever practicable, the lines of stress shall coincide with the lines of centers of gravity of cross-sections, and shall intersect at the joint point; and in cases where these conditions cannot be complied with, provision shall be made for a stiff connection between the members thus meeting.

Bed plates and friction rollers. Bed plates and bearing plates shall be truly planed on all sliding and rolling surfaces, and shall be so proportioned that the maximum pressure per square foot on the masonry will not exceed thirty-six thousand (36 000) pounds. They shall be securely anchored against upward and sideway motion.

The rollers shall be of steel; the pressure per lineal inch on same shall not exceed $\sqrt{540\ 000\ d}$, where d is the diameter of the rollers in inches.

The rollers and the rolling surface of bed plates shall be protected by wrought-iron casing to keep out foreign matters. Adjacent ends of consecutive spans shall have a common bed plate of wrought-iron at each side of bridge.

Anchorage. One end of each truss is to be firmly anchored to the masonry, and the other end so anchored as to prevent upward and sideway motion, but permitting longitudinal motion.

Quality of Materials.—Wrought-iron.

Character and finish. All wrought-iron must be tough, ductile, fibrous, and of a uniform quality for each class, straight, smooth, free from cinder pockets or injurious flaws, buckles, blisters or cracks.

As the thickness of the bar approaches the maximum that the rolls will produce, the same perfection of finish will not be required as in the thinner ones. No specific process or provision of manufacture will be demanded, provided the material fulfills the requirements of this specification.

Standard test pieces. 3. The tensile strength, limit of elasticity and ductility shall be determined from a standard test piece, not less than $\frac{1}{4}$ inch in thickness, cut from the full size bar, and planed and turned parallel; if the cross-section is reduced, the tangent between shoulders shall be at least twelve times its shortest dimension, and the area of the minimum cross-section in either case shall not be less than $\frac{1}{2}$ of a square inch and not more than 1 square inch. Whenever practicable, two

62 500 pounds per square inch, and the ultimate tensile resistance of the steel to be used in compression shall be 68 000 pounds per square inch. The tests to be made in the following manner:

16. From one ingot of each cast a round sample bar, not less than ¾ of an inch in diameter, and having a length not less than twelve diameters between jaws of testing machine, shall be furnished and tested by the manufacturer without charge. These bars are to be truly round, and shall be finished at a uniform heat, and arranged to cool uniformly, and from these test pieces alone the quality of the material shall be determined, as follows:

Tensile tests.

17. All the above-described test bars must have a tensile strength within 4 000 pounds per square inch of that specified; an elastic limit not less than one-half of the tensile strength of the test bar; a percentage of elongation not less than 1 200 000 ÷ the tensile strength in pounds per square inch, and a percentage of reduction of area not less than 2 400 000 ÷ the tensile strength in pounds per square inch. In determining the ductility, the elongation shall be measured after breaking on an original length of ten times the shortest dimension of the test piece, in which length must occur the curve of reduction from stretch on both sides of the point of fracture.

Finish and reduction of area on finished bars.

Finished bars must be free from flaws or cracks and must have a workmanlike finish, and round or square test pieces cut therefrom when pulled asunder shall have a reduction of area at the point of fracture as above specified.

Number of test pieces.

19. For each contract four such tests for reduction of area and four for bending, and one additional of each for each 50 000 pounds of steel, will, if required, be made by the contractor without charge, and if the purchaser is not satisfied that the reduction of area test correctly indicates the effect of the heating and rolling, such additional tests for tensile strength, limit of elasticity and ductility as he may desire will be made for him on test pieces conforming to the provisions of clause 3 at the rate of $5 each, or, if the contractor desires additional tests, he may make them at his own expense, under the supervision of the purchaser, the quality of the material to be determined by the result of all the tests in the manner set forth in the following clause:

Except for tensile strength, the respective requirements stated are for an average of the tests for each, and the lot of bars or plates from which samples were selected shall be accepted if the tests give such average results, but, if any test piece gives results more than 4 per cent. below said requirements, the particular bar from which it was taken may be rejected, but such tests shall be included in making the average.

If any test piece has a manifest flaw, its test shall not be considered. For each bar thus giving results more than 4 per cent. below the requirements tests from two additional bars shall be furnished by the contractor without charge, and if in a total of not more than ten tests two bars (or, for a larger number of tests, a proportionately greater number of bars) show results more than 4 per cent. below the requirements, it shall be cause for rejecting the lot from which the sample bars were taken. Such lots shall not exceed 20 tons in weight, and bars of a single pattern, plates rolled in universal mill or grooves, and sheared plates shall each constitute a separate lot.

Rivet steel.

Rivet steel shall have a specified tensile strength of 60 000 pounds per square inch, and test bars must have a tensile strength within 4 000 pounds per square inch of that specified, and an elastic limit, elongation and reduction of area at the point of fracture, as stated in clause 17, and be capable of bending double, flat, without sign of fracture on the convex surface of the bend.

Time of inspection.

The inspection and tests of the material will be made promptly on its being rolled, and the quality determined before it leaves the rolling-mill. All necessary facilities for this purpose shall be afforded by the manufacturer; but, if the inspector is not present to make the necessary tests, after due notice given him, then the contractor shall proceed to make such number of tests on the steel then being rolled as may have been agreed upon; or, in the absence of any special agreement, the number provided for in clauses 16 and 19, and the quality of such material shall be determined thereby.

Variation of weights.

A variation in cross-section or weight of rolled materials of more than 2½ per cent. from that specified may be cause for rejection.

Cast-iron.

Except where chilled iron is specified, all castings shall be tough gray iron, free from injurious cold shuts or blow-holes, true to pattern and of a workmanlike finish. Sample pieces 1 inch square cast from the same heat of metal in sand moulds shall be capable of sustaining on a clear span of 4 feet 6 inches a central load of 500 pounds when tested in the rough bar.

Workmanship.

Inspection.

Inspection of the work shall be made as it progresses, and at as early a period as the nature of the work permits.

All workmanship must be first-class. All abutting surfaces of compression members, except flanges of plate girders where the joints are fully spliced, must be planed or turned to even bearings so that they shall be in such contact throughout as may be obtained by such means. All finished surfaces must be protected by white lead and tallow.

The rivet holes for splice plates of abutting members shall be so accurately spaced that when the members are brought into position the holes shall be truly opposite before the rivets are driven.

When members are connected by bolts which transmit shearing

Rivets shall be used in preference to bolts for all rigid connections to resist shearing.

The webs of plate girders shall be spliced with a plate on each side.

The space between the edge of the piece and the edges of rivet holes shall be such that the metal will not crack or split by punching and riveting.

Adjustment. Lateral and sway-rods and all other members requiring adjustment shall be provided with adjusting screw threads and check nuts, convenient of access.

Sway bracing. The whole structure shall be thoroughly sway-braced, both horizontally and vertically.

Bolts, washers and nuts. Washers and nuts shall have a uniform bearing. All nuts shall be easily accessible with a wrench for the purpose of adjustment. No round-headed bolts will be allowed. All bolts through wood must be provided with wrought-iron washers under heads and nuts.

Railway floor. The cross-ties shall be eight (8) inches by eight (8) inches by twenty-two (22) feet, spaced fourteen (14) inches from center to center.

They shall be fastened by five-eighths ($\frac{5}{8}$) inch lag screws to guard timbers six (6) inches by eight (8) inches in section.

These guard timbers shall be lap-jointed and placed so that their central vertical planes shall be thirteen (13) inches outside of the central vertical planes of the outer rails.

Every fourth tie shall be bolted to the stringers by three-quarter ($\frac{3}{4}$) inch bolts.

Roadways. The ties and guard timbers shall be practically uniform in thickness.

The stringers shall be spaced about three (3) feet four (4) inches from center to center.

The flooring of the wagon-ways shall consist of two thicknesses of plank.

The under flooring shall be of creosoted timber planks three (3) inches thick, fastened on nailing pieces, also creosoted, secured on the top of the stringers.

The top flooring shall consist of white oak or yellow pine two and one-half ($2\frac{1}{2}$) inches thick and not more than eight (8) inches wide.

The flooring of the sidewalks shall be of white oak or yellow pine two (2) inches thick and not more than eight (8) inches wide, fastened to nailing pieces secured on top of stringers.

The under flooring of the wagon-ways and the sidewalk flooring shall be of the uniform thickness specified.

The under flooring of the wagon-way shall be fastened to the nailing pieces with seven (7) inch by seven sixteenth ($\frac{7}{16}$) inch wrought spikes.

The top flooring of the wagon-way shall be fastened by fifty (50) penny and the sidewalks by forty (40) penny nails of the best quality.

The stringers shall be securely fastened to the floor beams and in such a manner as to secure the requisite stiffness of the floor system.

The stringers for the railway floor shall be placed between the floor beams so as to reduce the height from base of rail to bottom of floor beams to a minimum.

Two wheel guards eight (8) inches by ten (10) inches, of white oak, shall be provided on each wagon-way. They shall be lap-jointed and securely bolted to the flooring by three-quarter ($\frac{3}{4}$) inch bolts placed four (4) feet apart.

The camber measured on the center line of pins of chords shall not be less than one eighteen hundredth ($\frac{1}{1800}$) of the span. The track ties shall be notched over the stringers sufficiently to secure them firmly in place. Camber.

The screens between the wagon-ways and railway shall be of tongued and grooved pine plank not more than four (4) inches wide, strongly built, and supported so as to resist a wind pressure of thirty (30) pounds per square foot. They shall be painted on both sides with three coats of approved metallic paint. Screens.

The outside railings shall be of approved design, and not less than four (4) feet high above floor of sidewalks. Railings.

They shall be supported directly by the floor-beam brackets and braced laterally with strong outside stays riveted thereto. Intermediate stays not more than ten (10) feet apart shall also be provided. The railings and floor timbers shall extend over all piers and make suitable connections with the masonry at the ends of the structure.

The timber shall be of first-class sound wood of the kinds specified. It shall be sawed true and out of wind, full-sized, free from wind shakes, large or loose knots, decayed brash or sap-wood, worm holes, or any defect impairing its strength or durability. The creosoted timber shall be prepared: Timber.

1st, by a thorough seasoning of the wood at a temperature not to exceed two hundred and thirty (230) degrees Fahrenheit, in a partial vacuum of twenty-four (24) inches of mercury, a sufficient length of time being used in this operation to avoid the cracking or splitting of the timber.

2d, by the injection into the wood under a pressure of not less than one hundred and fifty (150) pounds per square inch of not less than twelve (12) pounds of heavy creosote oil to each cubic foot of timber. This oil is to be of the best quality.

Sap-wood in timber to be creosoted will be accepted if otherwise sound.

All framing and trimming must be done before treatment.

Competent inspectors shall inspect the material at the mills and shops and make the required tests. These inspectors shall be mutually agreed upon. Before the final estimate is paid a thorough test of the Inspections and tests.

sidered. For each bar thus giving results more than 4 per cent. below the requirements, tests from two additional bars shall be furnished by the manufacturers without charge, and if in a total of not more than ten tests two bars (or, for a larger number of tests, a proportionately greater number of bars) show results more than 4 per cent. below the requirements, it shall be cause for rejecting the lot from which the sample bars were taken. Such lots shall not exceed 20 tons in weight, and bars of a single pattern shall each constitute a separate lot.

22. The inspection and tests of the material will be promptly made on its being rolled, and the quality determined before it leaves the rolling mill. All necessary facilities for this purpose shall be afforded by the manufacturer; but, if the inspector is not present to make the necessary tests, after due notice given him, then the manufacturer shall proceed to make such number of tests on the steel then being rolled as may have been agreed upon; or, in the absence of any special agreement, the number provided for in clauses 16 or 19, and the quality of such material shall be determined thereby.

23. A variation in cross-section or weight of rolled material of more than $2\frac{1}{2}$ per cent. from that specified may be cause for rejection.

32. All pin holes must be accurately bored at right angles to the axis of the members, unless otherwise shown in the drawings, and in pieces not adjustable for length no variation of more than $\frac{1}{32}$ of an inch will be allowed in the length between centers of pin holes; the diameter of the pin holes shall not exceed that of the pins by more than $\frac{1}{32}$ inch, nor by more than $\frac{1}{50}$ inch for pins under $3\frac{1}{2}$ inches diameter. Eye-bars must be straight before boring; the holes must be in the center of the heads, and on the center line of the bars.

All eye-bars belonging to the same panel, when placed in a pile, must allow the pin at each end to pass through at the same time without forcing. No welds whatever will be allowed in any part of any eye-bar.

33. To determine the strength of the eyes, full-size bars with eyes may be tested to destruction, provided notice is given in advance to the number and size for this purpose, so that the material can be rolled at the same time as that required for the structure.

35. In all cases where a steel piece in which the full strength is required has been partially heated, the whole piece must be subsequently annealed.

For the purpose of making tests of full-sized bars cover the process of annealing as well as mode of manufacture and dimensions and shape of head; all bars of any lot of eye-bars annealed at the same time shall be designated by a special mark, and shall be considered as one "lot." A complete record of the number and size of bars in each lot shall be preserved. A lot shall also consist of all bars of whatever length, of the same dimensions of cross-section or of same dimensions of head.

Any lot of steel bars from which full-sized samples are tested shall be accepted if the average of the tests shows a strength per square inch of original bar in those which break in the eye equal to that specified in clause 17; but if one-half of the full-sized test bars belonging to any lot break in the head, all bars of such a lot may be rejected.

All bars belonging to any lot may be rejected if the test bars of that lot break in the body and show an average ultimate resistance under 58 500 pounds per square inch in original section.

All full-sized bars which break in the eye at less than the strength here specified shall be at the expense of the manufacturer, unless he shall have made objection in writing to the form or dimension of the heads before making the eye-bars.

The costs of the bars and the tests of bars which break in the head, or which break in the body of the bar at less than 58 500 pounds per square inch, or which belong to rejected lots, shall be borne by the manufacturer; the expense of other full-sized tests shall also be borne by the manufacturer, but the bars shall be paid for at contract price, less its scrap value.

Supplementary Specifications for Steel Pins for Ohio River Bridge.

The ultimate tensile resistance of the steel to be used in all pins shall be 62 500 pounds per square inch.

(3.) The tensile strength, limit of elasticity and ductility shall be determined from a standard test piece, not less than $\frac{1}{4}$ inch in thickness, cut from the full-sized bar, and planed and turned parallel; if the cross-section is reduced, the tangent between shoulders shall be at least twelve times its shortest dimension, and the area of the minimum cross-section in either case shall not be less than $\frac{1}{4}$ of a square inch, and not more than 1 square inch. Whenever practicable, two opposite sides of the piece are to be left as they come from the rolls, but the finish of opposite sides must be the same in this respect. A full-sized bar, when not exceeding the above limitations, may be used as its own test piece. In determining the ductility the elongation shall be measured, after breaking, on an original length the nearest multiple of $\frac{1}{4}$ inch to ten times the shortest dimension of the test piece, in which length must occur the curve from reduction from stretch on both sides of the point of fracture, but in no case on a shorter length than 5 inches. Standard test pieces.

(16.) From one among the ingots of each cast two round sample bars, not less than $\frac{3}{4}$ of an inch in diameter, and having a length of not less than twelve diameters between jaws of testing machine, shall be furnished and tested by the manufacturer without charge. These bars are to be truly round, and shall be finished at a uniform heat, and arranged to cool uniformly, and from these test pieces alone the quality of the material shall be determined as follows: Test bars.

TABLE No. 1.

TESTS OF STEEL BY THE PHŒNIX BRIDGE COMPANY FOR THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY.

Heat.	Material.	Section of Test Specimen	Pounds per Square Inch at		Per Cent. of Final		Fracture.	Bending Test.	Accepted or Rejected.
			Elastic Limit.	Ultimate Strength.	Stretch in 8 inches.	Reduction.			
6669	Comp'n Steel.	¾''○	48.570	72.560	24.75	48.70	Hom.	.....	Accepted.
6669	"	"	47.890	71.660	24.75	43.20	"	......	"
6667	"	"	47.640	70.160	21.50	45.10	"	......	"
6667	"	"	48.560	72.250	25.00	49.30	"	......	"
6664	"	"	45.750	68.400	26.50	59.90	"	......	"
6664	"	"	46.140	68.700	25.00	57 50	"	......	"
6662	"	"	47.370	72.250	25.00	54.80	"	......	"
6662	"	"	47.370	71.770	27.50	56.50	"	......	"
6652	"	"	43.000	70.050	24.25	54.10	"	......	"
6652	"	"	43.540	68.540	25.75	57.60	"	......	"
6996	"	"	49.390	73.220	26.25	50.90	"	180° flat.	Rejected.
6996	"	"	48.560	71 800	26.25	54.50	"	" "	"
6982	"	"	46.000	69.250	27.00	58.80	"	" "	Accepted.
6984	"	"	45.820	71.360	26.25	57.80	"	" "	"
6994	"	"	46.150	69.960	26.25	57.50	"	" "	"
6985	"	"	47.700	70.940	27.00	56.20	"	" "	"
6983	"	"	47.250	70.170	25.00	60.40	"	" "	"
6981	"	"	45.820	67.300	26.75	59.20	"	" "	"
6992	"	"	45.350	68.020	26.00	54.90	"	" "	"
6986	"	"	48.430	70.700	27.50	58.80	"	" "	"
6987	"	"	44.800	67.800	25.00	45.50	"	" "	"
6990	"	"	45.300	65.600	26.00	62.10	"	" "	"
6960	"	"	46.500	71.300	24.25	53.50	"	" "	"
6849	"	"	46.200	68.530	26.50	61.30	"	" "	"
6850	"	"	45.610	70.080	30.00	58.00	"	" "	"

TABLE No. 2.

TESTS OF STEEL BY THE PHŒNIX BRIDGE COMPANY FOR THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY.

Heat.	Material.	Section of Test Specimen.	Pounds per Square Inch at		Per Cent. of Final		Fracture.	Bending Test.	Accepted or Rejected.
			Elastic Limit.	Ultimate Strength.	Stretch in 8 inches.	Reduction.			
6850	Comp. Steel.	¾''○	45.910	69.570	28.75	61.10	Hom.	180° flat.	Accepted.
6846	"	"	45.100	68.460	24.50	50.50	"	" "	"
6844	"	"	44.800	69.000	26.25	52.80	"	" "	"
6845	"	"	44.860	68.340	27.00	57.50	"	" "	"
6847	"	"	46.260	68.580	26.75	56.80	"	" "	"
6848	"	"	46.030	69.160	25.00	53.30	"	" "	"
6696	"	"	47.440	72.100	26.50	58.60	"		"
6698	"	"	48.840	71.580	23.50	45.70	"	......	"
6698	"	"	49.070	72.160	23.50	42.50	"	......	"
6663	"	"	48.340	72.090	26.25	55.60	"	......	"
6663	"	"	47.750	71.870	26.50	57.40	"	......	"
6692	"	"	49.170	72.450	24.50	41.60	"	......	"
6692	"	"	49.170	72.160	25.75	38.40	"	......	"
6688	"	"	47.030	69.000	22.50	42.30	"	......	"
6688	"	"	47.170	69.340	24.00	42.00	"	......	"
6674	"	"	46.290	67.940	26.75	50.00	"	......	"
6674	"	"	45.500	67.850	26.50	53.73	"	......	"

TABLE No. 5.

TESTS OF STEEL BY THE PHŒNIX BRIDGE COMPANY FOR THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY.

Heat.	Material.	Section of Test Specimen. Inches.	Pounds per Square Inch at		Per Cent. of Final		Fracture.	Bending Test.	Accepted or Rejected.
			Elastic Limit.	Ultimate Strength.	Strength in 8 inches.	Reduction.			
335	9 x $\frac{3}{8}$" pl.	1.015 x .402	40.690	68.630	30.00	38.48	Silky cup.	180° on self.	Accepted.
336	10 x $\frac{3}{4}$" pl.	1.015 x .760	37.850	62.740	26.87	55.26	Silky cup.	" "	"
338	12 x $\frac{1}{2}$" pl.	1.020 x .510	49.980	76.320	24.00	35.36	Ang. silky.	" "	"
331	12 x $\frac{1}{2}$" pl.	1.018 x .505	42.610	66.150	25.00	56.10	Ang. silky.	" "	"
350	16 x $\frac{3}{4}$" pl.	1.000 x .753	43.750	66.060	27.50	51.44	Ang. silky.	" "	"
394	17½ x $\frac{13}{16}$" pl.	1.020 x .791	37.180	63.710	28.12	50.05	Silky cup.	" "	"
398	17½ x $\frac{13}{16}$" pl.	1.023 x .796	34.270	62.640	23.75	37.84	Silky cup.	" "	"
332	19¼ x $\frac{1}{2}$" pl.	1.025 x .500	41.170	64.400	25.00	52.64	Silky cup.	" "	"
311	20 x $\frac{7}{16}$" pl.	1.030 x .430	41.100	63.230	25.00	54.74	Silky cup.	" "	"
593	20 x $\frac{9}{16}$" pl.	1.02 x 0.56	43.830	67.140	25.00	51.23	Silky cup.	" "	"
611	20 x $\frac{9}{16}$" pl.	1.01 x 0.57	45.140	67.270	25.00	53.87	Part cup and silky.	" "	"
610	20 x $\frac{11}{16}$" pl.	1.01 x 0.68	46.450	68.580	25.62	52.29	Part cup and silky.	" "	"
612	20 x $\frac{11}{16}$" pl.	0.99 x 0.68	46.210	62.600	25.62	53.66	Silky cup.	" "	"
578	20 x $\frac{11}{16}$" pl.	1.01 x 0.68	40.300	62.550	22.50	47.15	Ang. and silky.	" "	"
579	20 x $\frac{11}{16}$" pl.	.99 x 0.69	43.870	70.100	27.50	50.00	Silky cup.	" "	"
343	21½ x $\frac{5}{16}$" pl.	1.055 x .330	49.990	68.950	23.12	37.37	Silky cup.	" "	"
334	24 x $\frac{1}{2}$" pl.	1.025 x .501	41.680	68.370	24.75	47.50	Silky cup.	" "	"
399	30 x $\frac{1}{2}$" pl.	1.03 x 0.48	52.300	64.920	22.50	52.83	Silky cup.	" "	"
398	30 x $\frac{9}{16}$" pl.	1.015 x .548	44.950	62.930	23.75	44.50	Silky cup.	" "	"
406	30 x $\frac{9}{16}$" pl.	1.02 x 0.56	44.790	62.980	25.00	55.21	Silky cup.	" "	"
407	30 x $\frac{9}{16}$" pl.	1.00 x 0.56	39.980	63.120	26.25	52.28	Silky cup.	" "	"
390	30 x $\frac{9}{16}$" pl.	1.02 x 0.57	42.510	66.550	23.75	51.01	Silky cup.	" "	"
368	29 x $\frac{5}{8}$" pl.	1.020 x .597	48.610	69.460	25.62	49.86	Silky cup.	" "	"
396	30 x $\frac{9}{16}$" pl.	.992 x .557	45.070	70.590	26.87	42.60	Silky cup.		

TABLE No. 6.

TESTS OF STEEL BY THE PHŒNIX BRIDGE COMPANY FOR THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY.

Heat.	Material.	Section of Test Specimen. Inches.	Pounds per Square Inch at		Per Cent. of Final		Fracture.	Bending Test.	Accepted or Rejected.
			Elastic Limit.	Ultimate Strength.	Stretch in 8 inches.	Reduction.			
411	30 x $\frac{5}{8}$" pl.	1.01 x 0.61	39.900	68.410	23.12	45.13	Ang. and silky.	180° on self.	Accepted.
412	30 x $\frac{7}{8}$" pl.	1.05 x 0.86	41.760	68.280	24.37	42.01	Silky cup.	" "	"
415	30 x $\frac{5}{8}$" pl.	1.04 x 0.63	45.390	69.230	24.37	44.15	Silky cup.	" "	"
416	30 x $\frac{5}{8}$" pl.	1.01 x 0.61	43.260	69.110	22.50	39.90	Irreg. silky cup.	" "	"
400	30 x $\frac{5}{8}$" pl.	1.03 x 0.61	39.410	66.700	24.37	36.84	Ang. and silky.	....	"
401	30 x $\frac{5}{8}$" pl.	1.04 x 0.59	49.390	69.380	28.75	48.55	Silky cup.	....	"
402	30 x $\frac{5}{8}$" pl.	1.04 x 0.62	43.010	68.200	23.12	55.27	Silky cup.	....	"
403	30 x $\frac{5}{8}$" pl.	1.02 x 0.61	40.320	68.540	24.37	37.01	Irreg., ang. and silky.	....	"
389	30 x $\frac{5}{8}$" pl.	1.020 x .613	39.190	67.020	27.50	48.70	Irreg., ang. and silky.	....	"
393	30 x $\frac{5}{8}$" pl.	.995 x .613	42.630	68.050	24.	47.04	Irreg., ang. and silky.	....	"
395	30 x $\frac{5}{8}$" pl.	1. x .607	42.180	69.200	26.87	48.10	Irreg , ang. and silky.	....	"
397	30 x $\frac{5}{8}$" pl.	1.007 x .610	39.210	69.200	27.50	47.59	Irreg., ang. and silky.	....	"
359	30 x $\frac{5}{8}$" pl.	1.005 x .623	42.960	66.460	28.75	50.24	Silky cup.	....	"
360	30 x $\frac{5}{8}$" pl,	1.002 x .502	40.350	68.270	20.63	34.89	Silky ang.	180° on self.	"
404	30 x $\frac{5}{8}$" pl.	1.03 x 0.62	44.380	67.840	25.62	38.31	Ang. and silky.	" "	"
372	30 x $\frac{5}{8}$" pl.	1.020 x .626	43.700	65.780	26.87	41.86	Ang. and silky.	" "	"
382	30 x $\frac{5}{8}$" pl.	1.014 x .616	44.830	68.520	21.87	45.1	Ang. and silky.	" "	"
372	30 x $\frac{5}{8}$" pl.	1.003 x .624	41.550	63.280	25.	40.57	Ang. and silky.	" "	"
377	30 x $\frac{5}{8}$" pl.	1.035 x .631	41 350	66.620	26.25	46.50	Ang. and silky.	" "	"
383	30 x $\frac{11}{16}$" pl.	1.026 x .660	45.190	62.770	26.87	44.84	Ang. and silky.	" "	"
370	30 x $\frac{3}{4}$" pl.	1.023 x .751	38.010	70.670	23.12	32.29	Ang. and silky.	" "	"
348	30 x $\frac{3}{4}$" pl.	1.040 x .727	42.720	69.840	25.62	43.63	Silky cup.	" "	"
367	30 x $\frac{13}{16}$" pl.	1.035 x .795	41 920	65.620	25.62	40.93	Silky cup.	" "	"
378	30 x $\frac{7}{8}$" pl.	1.040 x .852	42.770	69.300	21.87	42.14	Silky cup.	" "	"
408	30 x $\frac{7}{8}$" pl.	1.03 x 0.86	37.390	68.200	27.50	47.04	Silky cup.	" "	"
409	30 x $\frac{7}{8}$" pl.	1.03 x 0.86	39.440	69.140	26.87	49.05	Silky cup.		

TABLE No. 9.

TESTS OF STEEL BY THE PHŒNIX BRIDGE COMPANY FOR THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY.

Heat.	Material.	Section of Test Specimen. Inches.	Pounds per Square Inch at		Per Cent. of Final		Fracture.	Bending Test.	Accepted or Rejected.
			Elastic Limit.	Ultimate Strength.	Stretch in 8 inches.	Reduction.			
257.149	7 x $1\frac{5}{8}''$	.49 x 1.63	40.690	64.060	26.	43.2	Silky.	....	Accepted.
257.149	7 x $1\frac{5}{8}''$	.49 x 1.65	40.720	63.840	27.8	51.5	Silky.	....	"
259.506	7 x $1\frac{5}{8}''$	.50 x 1.63	36.250	62.500	27.9	43.8	Silky.	....	"
259.526	7 x $1\frac{5}{8}''$	.49 x 1.65	36.420	61.980	27.8	44.3	Silky pitt.	....	"
261.527	7 x $1\frac{5}{8}''$	.51 x 1.60	42.280	60.240	28.6	56.1	Silky lam.	....	"
258.756	7 x $1\frac{13}{16}''$	.50 x 1.83	40.050	64.980	26.6	46.5	Silky.	....	"
261.324	7 x $1\frac{13}{16}''$	.51 x 1.84	39.280	63.060	30.7	50.8	Silky.	....	"
261.318	7 x $1\frac{13}{16}''$	.49 x 1.83	39.740	61.810	27.2	49.1	Silky.	....	"
261.114	7 x $1\frac{13}{16}''$	.49 x 1.84	38.430	63.020	27.	42.1	Silky.	....	"
261.315	7 x $1\frac{13}{16}''$	.50 x 1.82	37.860	65.090	28.	37.8	Silky.	....	"
259.410	7 x $1\frac{13}{16}''$	.57 x 1.84	35.690	64.040	26.90	37.5	Silky.	....	"
259.354	7 x $1\frac{13}{16}''$	.56 x 1.85	38.990	62.580	29.60	52.90	Silky.	....	"
259.153	7 x $1\frac{13}{16}''$	.51 x 1.85	39.570	62.560	32.2	56.6	Silky.	....	"
257.590	7 x $1\frac{13}{16}''$	.58 x 1.82	39.170	64.690	27.4	39.15	Silky gran.	....	"
257.413	7 x 2″	.51 x 2.02	36.880	62.400	30.9	39.6	Silky gran.	....	"
257.554	7 x $2\frac{1}{16}''$	.51 x 1.96	41.850	63.610	32.1	48.6	Silky.	....	"
259.654	7 x $2\frac{1}{16}''$	.51 x 1.96	39.360	60.980	30.0	43.5	Silky.	....	"
257.960	7 x $2\frac{1}{16}''$	.51 x 1.95	40.530	62.040	30.5	50.3	Silky.	....	"
21.541	8 x $1\frac{7}{16}''$ pl.	Diameter .823	40.230	65.040	22.	44.53	Silky.	....	"
21.561	8 x $1\frac{7}{16}''$ pl.	" .825	39.280	64.630	25.75	47.12	Silky.	....	"
21.553	8 x $1\frac{7}{16}''$ pl.	" .815	40.830	71.400	27.	53.63	Silky.	....	"
21.525	8 x $1\frac{7}{16}''$ pl.	" .812	40.750	71.260	27.5	54.12	Silky.	....	"
21.533	8 x $1\frac{7}{16}''$ pl.	" .832	40.000	66.220	25.	51.41	Silky cup.	....	"
21.529	8 x $1\frac{7}{16}''$ pl.	" .825	40.400	64.540	25.75	52.6	Silky.	....	"
21.549	8 x $1\frac{7}{16}''$ pl.	" .820	41.380	65.330	25.75	48.23	Silky cup.	....	"

TABLE No. 10.

TEST OF STEEL BY THE PHŒNIX BRIDGE COMPANY FOR THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY.

Heat.	Material.	Section of Test Specimen. Diameter. Inches.	Pounds per Square Inch at		Per Cent. of Final		Fracture.	Bending Test.	Accepted or Rejected.
			Elastic Limit.	Ultimate Strength.	Stretch in 8 inches.	Reduction.			
21 557	8 x $1\frac{1}{2}''$ pl.	.825	42.280	69.400	22.5	43.16	Silky.	......	
21 599	8 x $1\frac{13}{16}''$ pl.	.812	38.630	65.280	25.	45.41	Silky.	......	
21 603	8 x $1\frac{13}{16}''$ pl.	.814	41.600	65.340	27.5	48.	Silky.	......	
21 619	8 x $1\frac{13}{16}''$ pl.	.815	40.640	64.600	25.5	49.36	Silky.	......	
21 591	8 x $1\frac{13}{16}''$ pl.	.812	42.290	67.600	24.	42.62	Silky.	......	
21 598	8 x $1\frac{13}{16}''$ pl.	.825	40.590	63.600	25.	47.98	Silky.	......	
21 607	3 x $1\frac{7}{8}''$ pl.	.830	41.210	69.300	26.25	47.76	Silky.	......	
	Rivet Steel.	$\frac{3}{4}''$ round.	37.440	64.610	29.	47.	Cup silky.	180° flat.	
	"	"	41.990	61.800	28.75	50.9	Cup silky.	"	
	"	"	40.130	65.590	28.	42.8	Irregular silky.	"	
	"	"	39.170	64.510	30.	61.2	Cup silky.	"	
	"	"	37.840	64.670	29.25	51.3	Cup silky.	"	
	"	"	38.400	64.330	30.	62.0	Irregular silky.	"	
	"	"	37.620	63.110	31.75	63.	Irregular silky.	"	
	"	"	38.810	63.920	28.75	59.5	Irregular silky.	"	
	"	"	36.750	66.400	27.25	46.8	Irregular silky.	"	
	"	$\frac{15}{16}''$ round.	37.890	63.620	30.5	56.3	Cup silky.	"	
	"	"	38.090	62.500	31.	56.5	Cup silky.	"	

TABLE No. 13.

TESTS OF STEEL BY THE PHŒNIX BRIDGE COMPANY FOR THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY.

Link Plate.	Test Piece; length = 8 inches.	Pounds per Square Inch at		Per Cent. of Final		Fracture and Remarks.
		Elastic Limit.	Ultimate.	Reduction.	Elongation.	
These Link Plates varied from 60" x 48" x 2¼" to 78" x 25" x 2".	1 inch round.	28.530	61.140	50.3	27.5	Cup silky.
	1 "	28.020	60.440	39.8	25.5	Angular silky.
	1 "	26.880	58.340	63.0	30.0	Cup silky.
	1 "	28.020	57.450	62.1	31.25	Cup silky.
	1 "	24.260	60.280	51.6	25.00	Irregular silky.
	1 "	25.860	63.310	51.9	25.50	Angular silky.
	1 "	26.110	63.310	54.5	28.75	Cup silky.
	1 "	26.620	60.510	53.7	23.75	Cup silky.
	1 "	26.790	63.960	25.9	17.25	Irregular silky.
	1 "	26.114	63.552	50.3	25.25	Cup silky.
	1 "	26.114	61.400	53.2	31.5	Cup silky.
	1.25 "	33.190	63.990	44.68	27.5	Cup silky.
	1.16 "	35.740	64.340	37.68	26.5	Cup silky.

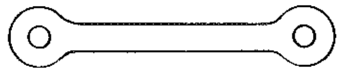
TABLE No. 14.

TESTS OF STEEL AND IRON ANGLES BY THE PHŒNIX BRIDGE COMPANY FOR THE CINCINNATI AND COVINGTON ELEVATED RAILWAY, TRANSFER AND BRIDGE COMPANY.

Size of Angle.			Test Piece; length = 8 inches.	Pounds per Square Inch at		Per Cent. of Final		Fracture and Remarks.
				Elastic Limit.	Ultimate.	Reduction.	Elongation.	
5 x 3"	25 pounds.	Steel.	1 x 0.32"	39.430	71.290	52.9	21.25	Angular silky.
"	41 "		1 x 0.55"	39.110	71.580	55.5	27.25	Cup silky.
"	49 "		1 x 0.625"	38.650	69.650	46.4	26.00	Cup silky.
6 x 4"	42 "		1 x 0.4"	39.440	71.105	54.3	23.75	Irregular silky.
"	44 "		1 x 0.43"	39.010	69.860	52.7	23.75	Angular silky.
"	72 "		1 x 0.74"	35.610	73.970	51.9	28.25	" "
"	72 "		1 x 0.73"	36.930	72.910	53.4	27.75	" "
"	84 "		1 x 0.85"	33.290	65.870	41.0	26.25	" "
"	84 "		1 x 0.84"	34.170	63.060	60.8	31.25	" "
6 x 6"	57 "	Iron.	1 x 0.49"	26.120	46.920	28.1	20.50	Fibrous.
"	57 "		1 x 0.50"	27.270	46.060	18.9	13.75	"
"	86 "		1 x 0.71"	29.600	50.600	25.3	21.75	"
"	86 "		1 x 0.70"	27.190	47.910	21.7	19.25	"
"	95 "		1 x 0.86"	25.110	45.910	23.9	20.00	"
"	95 "		1 x 0.86"	25.230	48.120	28.7	26.25	"
"	100 "		1 x 0.88"	24.420	47.220	25.5	22.50	"
"	100 "		1 x 0.90"	24.309	46.180	30.9	25.50	"
"	108 "		1 x 0.98"	24.540	47.000	21.2	21.25	"
"	108 "		1 x 0.97"	24.050	48.090	26.0	20.50	"
"	108 "		1 x 0.98"	24.670	48.730	30.1	25.00	"

TABLE No. 15.

Tests of full-size Steel Eye-bars by The Phœnix Bridge Company for the Cincinnati and Covington Elevated Railroad, Transfer and Bridge Company.

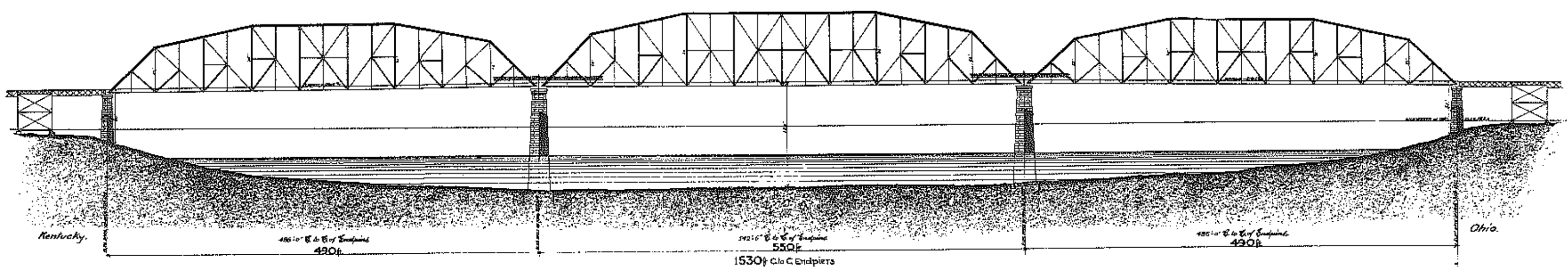


All pin-holes $6\frac{15}{16}$″ diameter.

Size of Bar.	Length c to c Pin-holes.	Per Square Inch of Original Section		Per Cent. Final			Fracture.	Accepted or Rejected.
		Elastic Limit.	Ultimate.	Stretch.		Contraction.		
				in.	in 12″.			
					Per Cent.	Per Cent.		
7 x $1\frac{5}{8}$″	26′ 7.9″	40.756	63.085	24 ft. 14.8 p. c.	$35\frac{8}{10}$	$48\frac{4}{10}$	Silky.	Accepted.
7 x $1\frac{3}{8}$″	20′ 11.9″	41.000	64.130	18 ft. 20.5 p. c.	$34\frac{2}{10}$	$41\frac{3}{10}$	Silky.	"
7 x $1\frac{13}{16}$″	27′ 9.5″	36.930	60.700	25 ft. 12 p. c.	$18\frac{3}{10}$	$13\frac{3}{10}$	Broke in head. Gran. and crys.	"
7 x $1\frac{1}{16}$″	27′ 9.5″	38.743	63.370	28 ft. 15.7 p. c.	$38\frac{1}{3}$	$43\frac{8}{10}$	Granular, 25 %. Silky, 75 %.	"
7 x $1\frac{1}{16}$″	27′ 9.5″	39.740	63.200	25 ft. 17.7 p. c.	$36\frac{2}{3}$	$45\frac{7}{10}$	Silky center, granular. Edges, ragged.	"
7 x $1\frac{1}{16}$″	27′ 9.5″	40.570	63.020	25 ft. 14.4 p. c.	$32\frac{1}{2}$	$44\frac{7}{10}$	Ragged, silky.	"
7 x $1\frac{13}{16}$″	27′ 9.5″	37.140	61.790	25 ft. 17.1 p. c.	$36\frac{2}{3}$	$43\frac{8}{10}$	Silky center, granular ragged edges.	"
7 x $1\frac{13}{16}$″	26′ 8″	36.048	59.290	24 ft. 17.6 p. c.	$42\frac{1}{2}$	$54\frac{5}{10}$	Center cupped silky. Edges granular.	"
7 x $1\frac{5}{8}$″	26′ 7.9″	39.380	62.910	24 ft. 20.1 p. c.	$36\frac{2}{3}$	$48\frac{1}{10}$	Silky, granular, ragged edge.	"
7 x $1\frac{1}{2}$″	26′ 8″	38.460	62.778	24 ft. 16.7 p. c.	35	$50\frac{3}{10}$	Silky center. Ragged gran. edges.	"
7 x $1\frac{13}{16}$″	26′ 8″	36.881	59.032	24 ft. 19.4 p. c.	40	$50\frac{8}{10}$	Silky cup. center. Ragged gran. edges.	"
7 x 2″	26′ 8″	39.080	62.240	24 ft. 13 3 p. c.	$40\frac{8}{10}$	$40\frac{7}{10}$	Silky cup. center. Ragged gran. edges.	"
7 x $2\frac{1}{16}$″	26′ 8″	37.520	53.880	24 ft. 7.0 p. c.	$8\frac{3}{10}$	Broke in head	Granular center. Finely crys. edges.	"
7 x $1\frac{5}{16}$″	26′ 7.6″	40.836	62.910	23 ft. 20.75 p. c.	40	56.16	Silky center, fine, granular on edges.	Rejected.
7 x $1\frac{3}{16}$″	26′ 7.6″	38.600	61.014	23 ft. 13.6 p. c.	37.5	52.7	Silky center, fine, granular on edges.	Accepted.
7 x $1\frac{1}{4}$″	26′ 7.6″	43.620	66.827	23 ft. 13.6 p. c.	17.5	....	Broke in head.	"
7 x 1″	26′ 7.6″	42.846	59.187	23 ft. 9.3 p. c.	11.66	....	Broke in head.	"
7 x 1″	26′ 7.6″	42.846	64.844	23 ft. 15.04 p. c.	37.5	57.4	Silky cup.	"
7 x $2\frac{1}{16}$″	26′ 7.6″	38.400	62.600	24 ft. 17.2 p. c.	38.3	55.1	Silky.	"
8 x $1\frac{13}{16}$″	23′ 10.8″ *B*	34.900	58.469	20 ft. 17.8 p. c.	37.5	45.8	60 % silky.	"
8 x $1\frac{7}{16}$″	34′ 6.5″ *B*	38.477	63.950	31 ft. 14.3 p. c.	35.8	51.2	Silky at 45 %.	"
8 x $1\frac{13}{16}$″	23′ 10.8″ *B*	33.337	58.656	:0 ft. 21.7 p. c.	36.6	56.2	70 % silky cup.	"
8 x $1\frac{3}{16}$″	22′ 7.0″ *B*	34.060	56.200	20 ft. 16.4 p. c.	36.7	54.6	70 % silky cup.	"
8 x $1\frac{1}{4}$″	22′ 7.0″ *B*	44.800	72.750	20 ft. 17.5 p. c.	37.5	56.3	60 % silky.	"
7 x $2\frac{1}{8}$″	27′ 1.4″	40.230	59.520	25 ft. 8.96 p c.	11.6	....	Broke in head. Fine granular.	Rejected.
7 x $1\frac{5}{8}$″	27′ 1.4″	39.160	64.850	25 ft. 18.26 p. c.	30.8	51.2	Silky gran. edges.	Accepted.
7 x $1\frac{13}{16}$″	27′ 1.4″	38.000	60.200	25 ft. 16.86 p. c.	33.33	56.6	Silky gran. edges.	Rejected.
7 x 2″	27′ 1.4″	39.860	55.370	25 ft. 7 p. c.	8.35	....	Broke in head. Coarse gran.	"
7 x $2\frac{1}{8}$″	27′ 1.4″	......	38.900	....	....	....	7″ pin used with $\frac{5}{16}$ bushing.	"
7 x 2″	27′ 1.4″ Reannealed.	40.600	61.300	25 ft. 13.3 p. c.	39.1	48.7	Broke in head. Ragged, silky.	Accepted.
7 x $1\frac{13}{16}$″	27′ 1.4″	39.000	62.440	25 ft. 17.66 p. c.	32.5	....	Broke in head. Fine granular.	"
7 x $1\frac{5}{8}$″	27′ 1.4″	40.720	60.400	25 ft. 9.33 p. c.	13.33	....	Broke in head. Fine granular.	Rejected.
7 x $1\frac{5}{8}$″	27′ 1.4″	38.840	61.450	25 ft. 11.7 p. c.	16.66	....	Broke in head. Fine granular.	"
7 x $1\frac{3}{8}$″	27′ 1.4″	40.000	64.170	25 ft. 16.2 p. c.	33.3	46.4	Silky, crys. edges.	"
7 x $1\frac{3}{8}$″	24′ 11.9″	40.100	56.650	22 ft. 6.2 p. c.	6.66	....	Broke in head. Fine crys., coarse on edges.	"
7 x $1\frac{5}{8}$″	27′ 1.4″	38.670	60.792	25 ft. 14.37 p. c.	34.2	4.52	Silky cup. center. 20 % gran. on edges.	Accepted.
7 x $1\frac{3}{8}$″	27′ 1.4″ Reannealed.	36.200	57.670	25 ft. 14.4 p. c.	39.2	49.5	50 % silky cup. 50 % silky jagged.	"
7 x $1\frac{5}{8}$″	27′ 1.5″	39.680	61.670	25 ft. 14.8 p. c.	35.0	43.3	Silky cup, center; 25 % gran. edges.	"
7 x $1\frac{3}{8}$″	25′ 1.1″	38.689	62.660	24 ft. 15.85 p. c.	34.2	42.7	Silky center, gran. jagged edges.	
7 x $1\frac{1}{16}$″	27′ 9.3″	42.070	69.980	26 ft. 11.45 p. 3.	24.58	46.2	25 % granular. 75 % silky cup.	"
7 x 1″	27′ 7.9″	45.680	72.160	25 ft. 15.79 p. c.	33.75	43.2	Silky ⅓ cupped.	"
7 x $1\frac{1}{16}$″	27′ 9.4″	42.690	67.300	26 ft. 14.2 p. c.	30.4	50.1	Silky cupped.	"
7 x $1\frac{3}{8}$″	20′ 11.9″	38.860	60.860	19 ft. 19.3 p. c.	35.0	43.4	Silky jagged center, 12 % gran. edges.	"
7 x $1\frac{5}{8}$″	26′ 8.0″	38.080	60.460	24 ft. 14.5 p. c.	35.0	39.5	55 % silky center. 45 % granular.	"
7 x $1\frac{13}{16}$″	26′ 8.0″	39.540	61.800	24 ft. 14.3 p. c.	39.1	47.2	Jagged, silky.	"
7 x 2″	26′ 8.0″	37.360	59.160	24 ft. 15.5 p. c.	36.6	50.3	Silky cupped.	"
7 x $2\frac{1}{16}$″	26′ 8.0″	36.800	60.400	24 ft. 15.6 p. c.	38.3	50.8	Silky ½ cupped.	"
7 x $1\frac{13}{16}$″	27′ 9.5″	38.780	60.000	26 ft. 15.5 p. c.	40.0	51.06	Silky cupped; 15% gran. edges.	"
7 x $1\frac{13}{16}$″	27′ 9.6″	38.900	62.270	26 ft. 16.1 p. c.	25.8	46.8	Silky cupped, 10 % fine gran. edges.	"

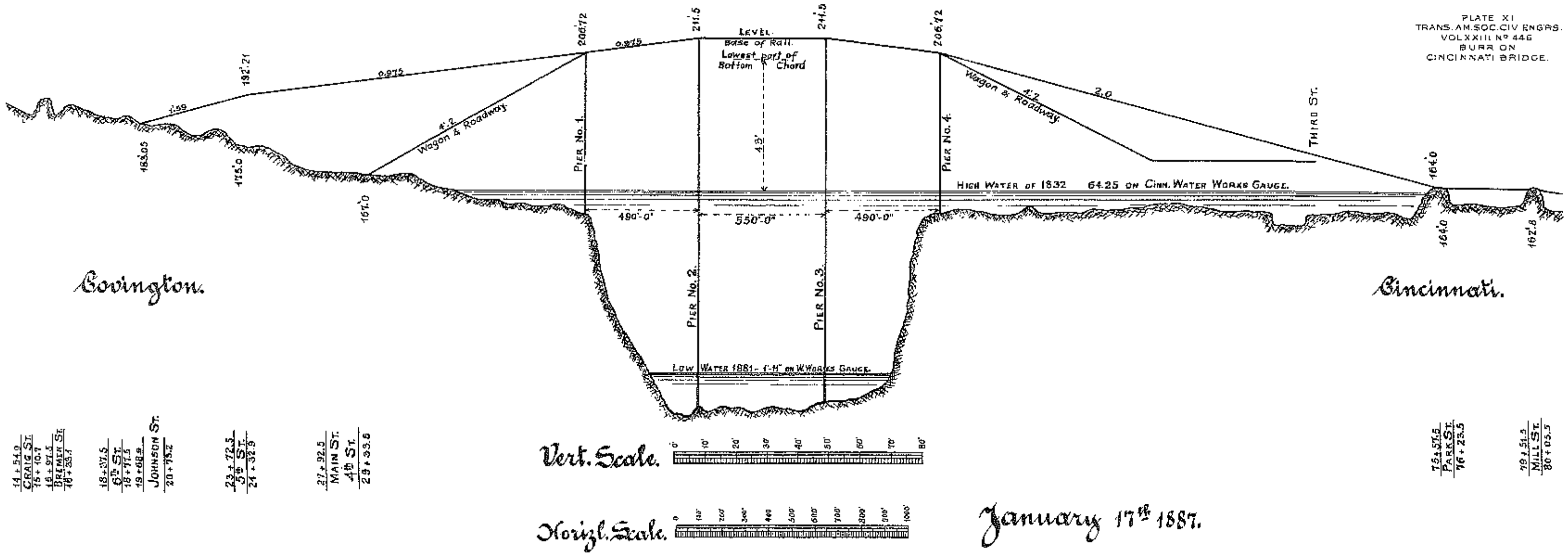
Note.—"*B*" indicates Bessemer steel; all others are open hearth metal.

PLATE X.
TRANS. AM. SOC. CIV. ENG'RS
VOL. XXIII Nº 446
BURR ON
CINCINNATI BRIDGE.



GENERAL ELEVATION
OF THE
RIVER SPANS – OHIO RIVER BRIDGE.
THE COVINGTON AND CINCINNATI ELEVATED RAILROAD
AND TRANSFER AND BRIDGE CO.
DESIGNED, CONSTRUCTED & ERECTED BY,
THE PHOENIX BRIDGE COMPANY,
ENGINEERS & CONTRACTORS
PHOENIXVILLE, PA.
1888.

PLATE XI
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXIII. Nº 446
BURR ON
CINCINNATI BRIDGE.



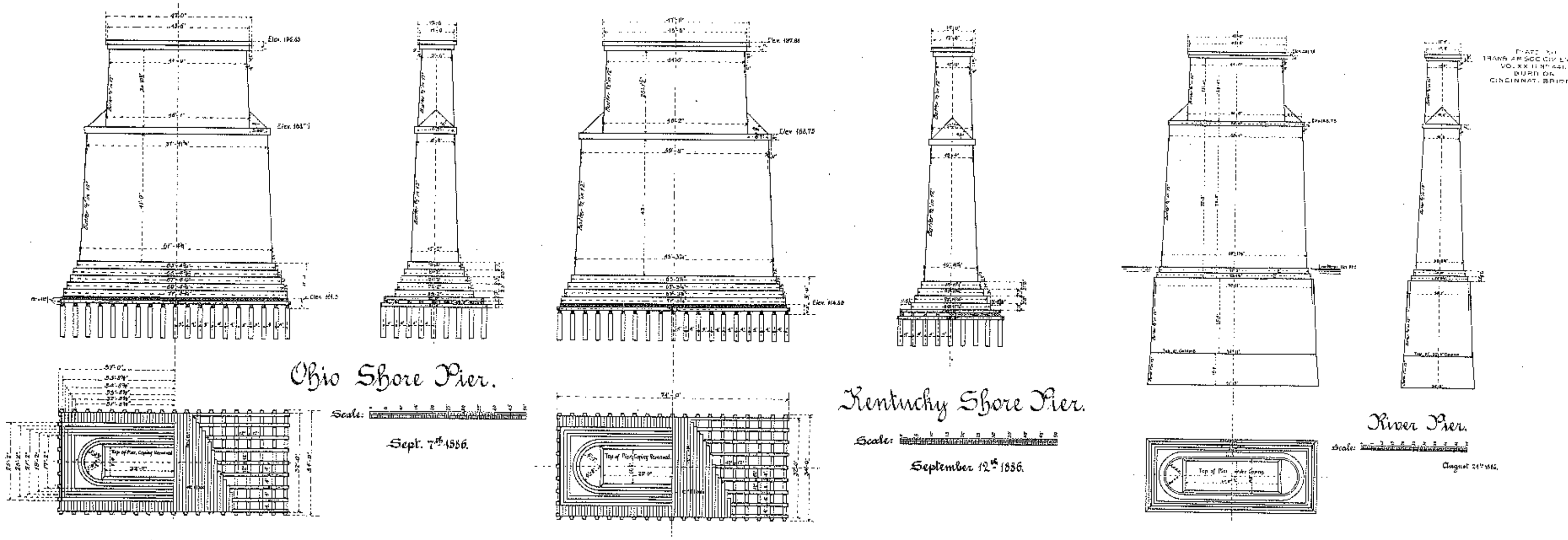
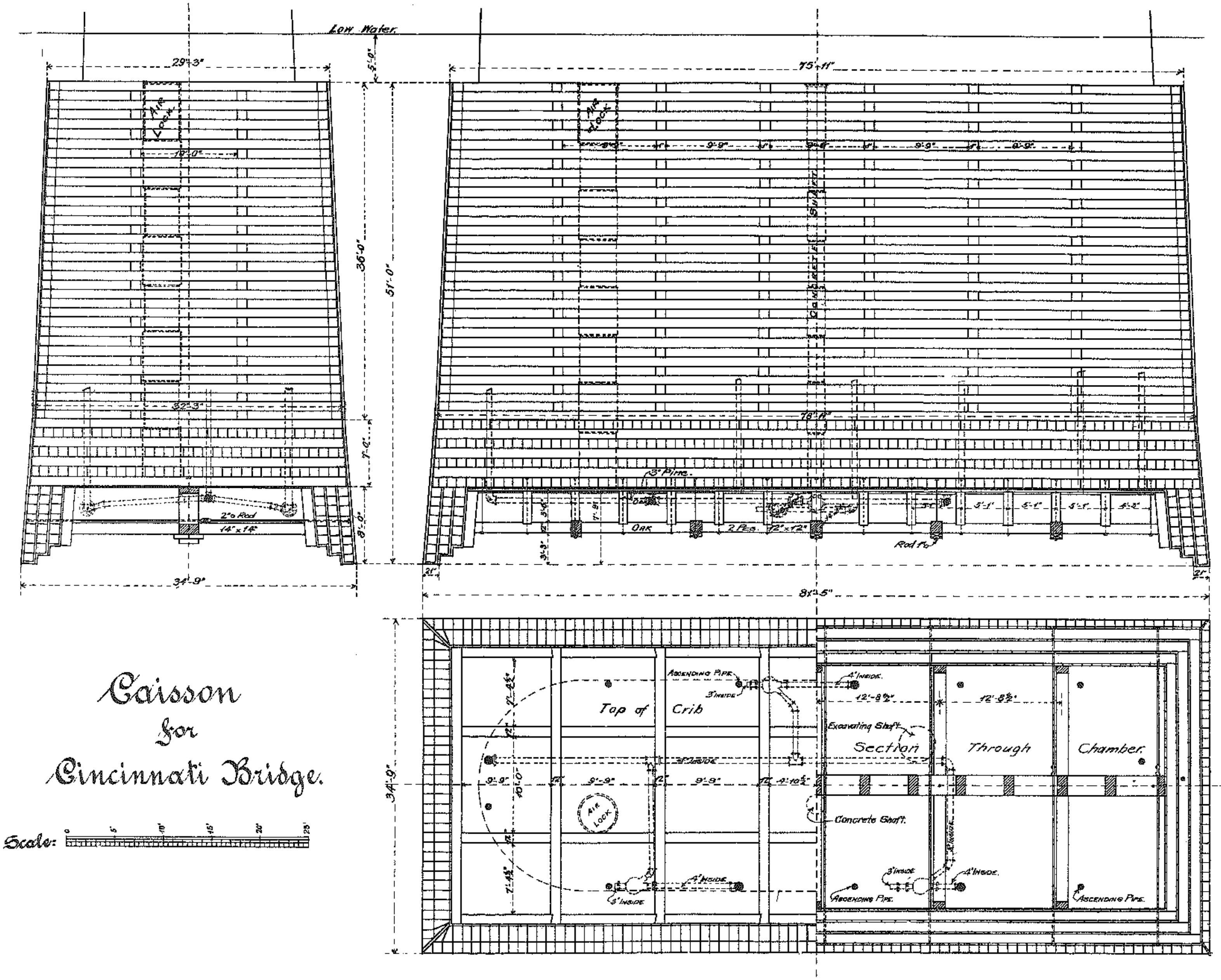
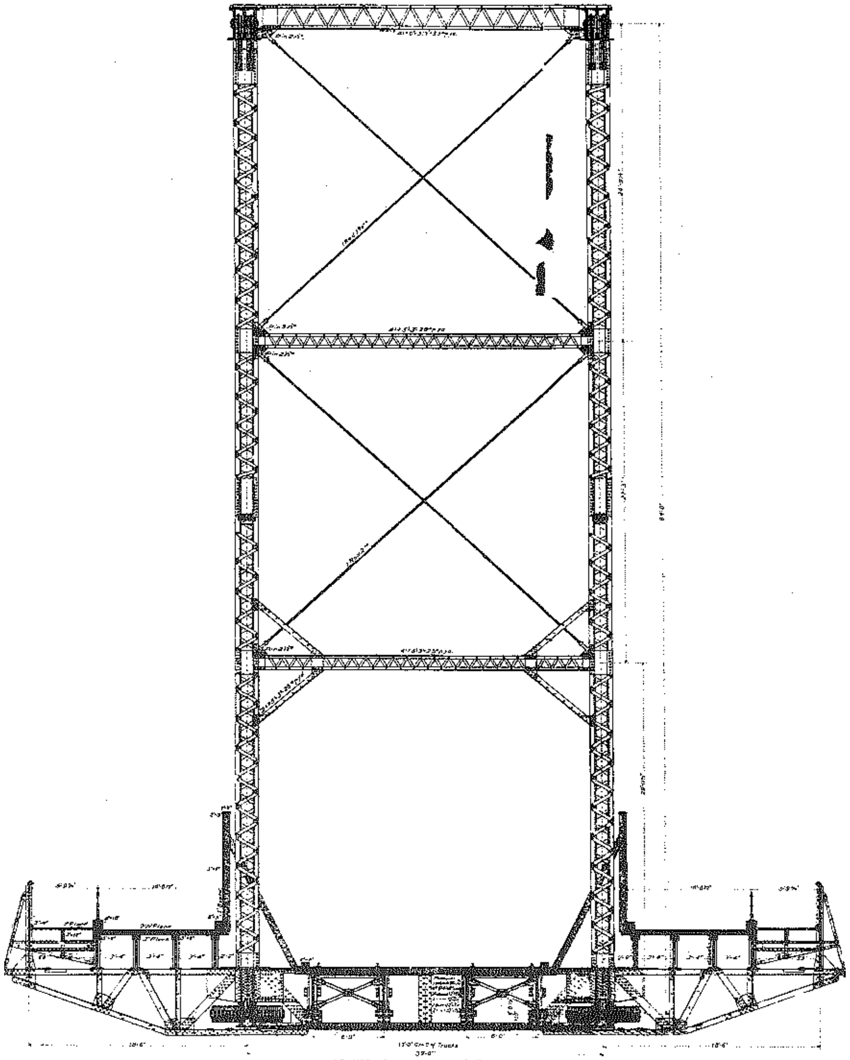

TRANS. AM. SOC. CIV. EN.
Ohio Shore Pier.
Scale:
Sept. 7th 1886.
Kentucky Shore Pier.
Scale:
September 12th 1886.
River Pier.
Scale:
August 21st 1886.
Top of Pier, Coping Removed

PLATE XIII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL XXIII Nº 446
BURR ON
CINCINNATI BRIDGE.

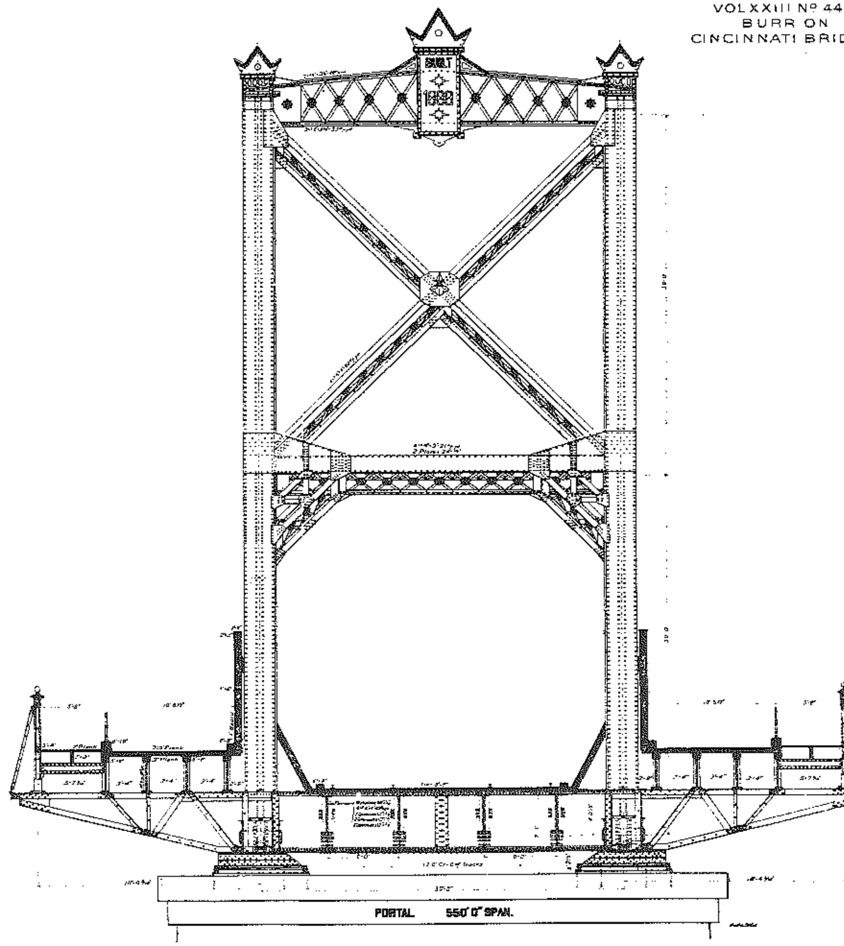


Caisson for Cincinnati Bridge.

PLATE XIV
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXIII Nº 446.
BURR ON
CINCINNATI BRIDGE.



CENTRE SECTION 550' 0" SPAN



PORTAL 550' 0" SPAN.